COMPARISON OF INTERNAL FIT OF METAL COPINGS FABRICATED WITH LASER SINTERING TECHNIQUE AND LOST-WAX TECHNIQUE, PRE AND POST FIRING: AN IN VITRO STUDY

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I offer my prayer to the Almighty

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CERTIFICATE

This is to certify that the dissertation entitled **"COMPARISON OF INTERNAL FIT OF METAL COPINGS FABRICATED WITH LASER SINTERING TECHNIQUE AND LOST-WAX TECHNIQUE PRE AND POST FIRING: AN IN VITRO STUDY"** BY **DR. MOHAMMED.A**, post graduate student (M.D.S), Prosthodontics And Crown Bridge (branch – I), KSR Institute of Dental Science and Research, Thiruchengode, submitted to the Tamil Nadu Dr. M.G.R. Medical University in partial fulfilment for the M.D.S. degree examination (october 2014) is a bonafide research work carried out by him under our supervision and guidance.

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INTRODUCTION

Anterior and posterior teeth have been extensively restored, with single crown and bridges, for function, speech, comfort and aesthetics. Casting alloys have been an important part of restorative dental treatment for more than a century. Restorations commonly fabricated for fixed prosthetic treatment, such as inlays, onlays, crowns and fixed partial dentures are fabricated in the dental laboratory using the lost-wax technique, introduced by Taggart in 1907.

Metal-ceramics are still the most widely used material for fabricating complete coverage crowns and fixed partial dentures and are considered the gold standard due to its clinical success and longevity. Accuracy of the fit of cast metal restorations has always remained as one of the primary factors in determining the success of a restoration. A well fitting restoration needs to be accurate both along its margins as well as with regard to its internal surface. [15,47,54.]

The marginal and internal fit of the metal-ceramic restorations have been the focus of various investigations and is an important factor for the clinical success and longevity of these restorations. The presence of a marginal gap can lead to dissolution of the luting agent, creating an area for biofilm development that may cause caries and periodontal disharmony. Poor internal fit of a coping can increase the thickness of the cement and thus influence the mechanical stability of dental restorations [20.] Based on literature review the acceptable vertical marginal gap ranges between 10-160µm and internal gap ranges between 81 to 136µm.[56]

Conventional casting methods require patterns for casting procedure. The fabrication of acceptable patterns is an important variable that can affect the marginal and internal fit of cast restorations. The techniques for pattern formation employ materials like inlay casting wax, auto-polymerizing resins, and light cured resins. Wax is popular because of its desirable properties like adequate strength, rigidity, and ease of manipulation and absence of residue on burnout. But distortion of wax pattern like shrinkage due to relaxation of internal stress contributes to detrimental effects on cast restorations.

Direct Metal Laser Sintering (DMLS) a more advanced technique that combines low cost with the added benefits of CAD/CAM precision fit, reduced marginal adjustments, bio-compatible material, consistent framework with no casting defects, all backed up by electronic strength check, takes into the consideration of all disadvantages of lost wax technique and would be of great help to the laboratory personnel to replace the cast metal restoration preparations. There are numerous systems available for rapid production of the fixed partial dentures for dental laboratories using CAD/CAM technology. The CAD/CAM process was introduced for application over two decades ago to prepare ceramic inlays and veneers. Several research groups have presented favorable reports on CAD/CAM restorations in different dental applications.

Most CAD/CAM frameworks are manufactured from ceramic typically zirconia, A new CAD/CAM laser melting technology for the fabrication of metal copings for metal-ceramic crowns, by using Direct-Metal Laser sintering of chrome- cobalt alloy have been recently introduced. DMLS can replace the zirconia machining process to create a metal-based alternative. This high tech process is sometimes described as '3D printing' because it builds up each framework in a series of successive thin layers (0.020mmthick). A high-powered laser beam is focused onto a bed of powdered metal (medical grade Co-Cr) and these areas fuse into a thin solid layer. Another layer of powder is then laid down and the next 'slice' of the framework is produced and fused with the first. When the complete process is over, the solid copings and bridge frameworks are taken from the machine, sand blasted, polished, inspected and ultrasonically cleaned.

The machine can create hundreds of units at a time and the cost of each one is relatively low. The used powder that remains unused is filtered and can be reused in the next batch so that there is very little waste of material that can keep running costs to a minimum.

According to the manufacturer, a 50W Yb fiber Laser is used as the power source and computer software is used for controlling the manufacturing cycle. The Direct metal laser sintering system when compared to that of lost-wax casting technique has the capability of producing up to 90 units per running cycle and is easy to use. They produce accurate restorations and have simplified post processing procedures.[16]Though the physical and mechanical properties of the Direct-Metal-Laser-sintered crowns are well accepted, their accuracy of fit and marginal adaptation is not well documented. Their ability to withstand the firing temperature of ceramic without distortion is another area of concern.

Many of the previous studies have focused on the evaluation of marginal and internal fit of cast restorations fabricated by different preparation designs, impression techniques, die preparations, spacer thickness, pattern fabrication, investment material and conventional casting technique. Even a recent study conducted was to evaluate the marginal and internal fit of DMLS with that of conventional copings. In view of the above the present In-vitro study was conducted to compare the marginal and internal fit of conventional coping with that of DMLS before and after porcelain firing.

Aim

Aim of this study to compare the internal fit of metal copings fabricated using lost-wax and direct metal laser sintering technique, before and after firing.

Objectives

1. The volumetric measurement of the internal gap between the master die and coping fabricated by lost-wax technique with the help of a silicone material.
2. The volumetric measurement of the internal gap between the master die and coping fabricated by direct metal laser sintering technique with the help of a silicone material.
3. To measure the internal gap between the master die and coping fabricated by lost-wax technique at two different points in mesio-distal cross section with the help of SEM(scanning electron microscope).
4. To measure the internal gap between the master die and coping fabricated by direct metal laser sintering technique at two different points in mesio-distal cross section with the help of SEM(scanning electron microscope).
5. To compare the internal gap between the master die and coping fabricated using the conventional lost-wax technique, direct metal laser sintering and layering done using the conventional manual layering method.

LITERATURE REVIEW

Fusayama T et al (1959) [15] in their study on dimensional accuracy of restorations stated that contraction of wax pattern during solidification and cooling and elastic recovery after removal are the important factors for shrinkage of wax patterns after removal from the preparation. Difference in setting expansion of the investment and wax pattern will also distort the wax pattern or mould and restrict investment expansion. Casting shrinkage of metal varies according to form and size of the moulds. The cement space and the surface roughness should also be in measuring dimensional change of casting.

Ebrashi MKE, Craig RG and Peyton FA, (1969) [12]this article on "Experimental stress analysis of dental restoration-part III showed the concept of geometry of proximal margins" reported that the chamfer and round type marginal preparation had low stress concentration when loaded vertically. Rounding the axio-gingival line angle in shoulder geometry experiments reduced stress concentration factor upto 50%.

J. Valderhaug and J.M.Birkeland(1976)[52] concluded from their studies that the fixed prosthesis when adequately made and patient maintains a satisfactory oral hygiene, little damage is likely to be caused to the periodontal tissues when the crown margins are located supragingivally**.**

Cooney JC, Doyle TM, and Caputo Angelo A (1979) [8]a study was done to evaluate the surface smoothness and fit of casting obtained by two phosphate bonded investments and one calcium sulfate investment. The results revealed that all phosphate-bonded methods were comparable to each other and superior to that obtained with calcium sulfate investment.

Ogura .H, Constantin N. Raptis, and Kamal Asgar (1981)[36]studied the inner surface roughness of complete cast crowns made by centrifugal casting machines, and stated that trailing portion of complete casting had rougher surface than the leading portion,, higher mold and casting temperature produced rougher casting more in base metal alloy, sandblasting reduced rough surface but produced scratches, the morphology and roughness profile of the original cast surface differed considerably with the type of alloy used.

Plekavich EJ, Joncas JM, (1983) [39]this study compared the adaptation of the margins of gold crowns produced from three impression–die combinations. All crowns were cemented on to prepare natural teeth, sectioned, the degree of marginal openings was measured and the groups were compared. Crowns produced on silver dies from polysulfide impressions had smaller opening than crowns made on dies of improved stones.

Luis Blanco, Dalmau, Carrasquillo,Alberty HC, and Parra JS (1984) [30]this study suggested that Nickel is potentially allergic material cause's contact dermatitis more common in women. Induction and elicitation are the two phases, where induction is period from initial contact with the chemical after initial contact, were as elicitation phase is a period from re-exposure to the chemical until dermatitis appears. They recommended a patch test to be performed on every patient who is treated with prosthesis that contains nickel to detect nickel sensitivity.

H.W.Dedmon(1985) [10] the purpose of the study was to correlate the marginal fit of cast crowns made by commercial dental laboratories with the design of the margin. Based on Christian's Study39µmwas used as the maximum acceptable width of margin opening when the fit was evaluated on the dies.

Fransson B, Oilo G, Gjeitanger R. (1985) [14] conducted a clinical study for comparison of the fit of the metal ceramic crowns by means of replica technique and showed significant difference due to multifactorial reasons. The study has stated that the film thickness of the cementing material and their die manufacture and impression techniques are all of to be considered.

J.A.Moore,DDS, N.Barghi,DDS,MAC. E.Brukl,Phd, and D.A.Kaiser, DDS, MSD. (1985)[34] on their study on marginal distortion of cast restorations induced by cementation evaluated precementation and post cementation measurements of the marginal discrepancy of the crowns. They demonstrated that all the crowns showed marginal discrepancies during cementation and the vertical heights also increased significantly.

Ivy Schwartz (1986) [42]this study suggested few methods to evaluate and improve the marginal adaptation of restorations. The suggestions were, 1. Over waxing the margins of wax pattern by 0.25mm to 0.5mm with soft red utility wax so that the margins could be refined on the die before seating on the tooth. 2. Removing wax from the internal surface of wax pattern, 3. Internal relief of cast restoration by sandblasting, mechanical milling with burs with and without disclosing wax, acid etching (aquaregia) electrochemical milling, 4. Occlusal venting for escape of excess cement, 5.Devices to apply seating forces, 6.Vibration during cementation, 7.Die spacer application.

S.H.Davis, J.R.Kelly, and S.D. Campbell (1989) [9] a method to improve the fit of castings by use of light bodied condensation silicone material was tested. Eighteen full coverage castings were made on individual resin dies and divided into two groups. The experimental groups were adjusted internally to a uniform pre-cementation space a light body silicon impression material was used as a disclosing agent for binding of castings on the axial or occlusal walls. Measurements of marginal fit were made with a light microscope using a filar eyepiece both externally and internally by sectioning after cementation with a zinc phosphate cement. Result demonstrated a significant improvement in marginal seal and occlusal seating in the experimental group compared with the control group. The condensation silicon material proved to be an appropriate research tool for nondestructive, three- dimensional evaluation of the post-cementation space and offers a new method of evaluation of cement thickness because seating was found to be not significantly different from that with zinc phosphate cement.

Holmes JR, Bayne SC, Holland GA, and Sulik WD (1989)[20]described that best way to visualize the marginal and internal discrepancy is by embedded and sectioned specimens or direct visualization of the specimens or their replicas. The fit of a cast can be defined best in terms of the “misfit” measured at various points between the castings surface and the tooth. Measurements between the castings and the tooth can be made from pints along the surface at the margin, on the external surface of the casting.

M.Bagby, S.JMarshall, and G.W.Marshall (1990)[4] stated that the selection of alloys used for metal ceramic restorations should satisfy the physical ,biological and functional requirements along with being thermally, mechanically and chemically compatible with veneering porcelain without compromising esthetics.

Hung et al (1990) [22] the marginal fit of Dicor, Cerestore and porcelain-fused-metal crowns was evaluated. Ten premolars free of caries were prepared for each type of restoration and crowns were made. The marginal openings were significantly increased after cementation and thermo cycling. The results showed PFM crowns had better marginal fit than Dicor and Cerestone crowns.

StigKarlsson (1993) [46]conducted a study evaluated by means of a replica technique on the fit or adaptation of Procera titanium crowns to the stone die and in vivo to the tooth before cementation stated that the marginal adaptation of the procera crowns was superior to and significantly better than axial and occlusal surfaces.Marmara university, Istanbul, Turkey

DenizGemalmaz, and HasanAlkumru DDS (1995) [11] investigated the marginal fit changes that occur during the porcelain firing cycles of palladium copper and nickel chromium copings with chamfer and shoulder finish lines under scanning electron microscopy. The highest marginal fit change of the copings was found at the first porcelain firing cycle (degassing). The non precious metal alloy copings revealed smaller marginal fit change than the precious metal alloy copings.

H. Ogura (1995) [36] indicated from his studies that the casting shrinkage of thin walled castings is influenced by size and casting pressure. The casting shrinkage of a thin walled casting is influenced by the temperature gradient in the alloy and the resultant time difference in alloy solidification as well as the supply of the molten metal alloy in the mould.

S.Glagys, B.VanMeerbeek, S.Inokoshi, G.Willems,M.Braem, P.Lambrechts, and G. Vanherle. (1995)[17] conducted a 3 year clinical and semiquantitative investigation on marginal analysis of four tooth coloured inlay systems. The clinical evaluation was preformed with a mirror and explorer by two clinicians separately, and the marginal analysis was conducted microscopically on replicas (SEM X 200). Replicas were made for the evaluation in the scanning electron microscope (XL 20 Scanning Electron Microscope). The marginal quality was determined by means of computer – aided semiquantitative marginal analysis at a magnification of 200X.

ElaineR.Schilling, BarbaraH.Miller, RonaldD, Woody, AmpW.Miller. (1999) [13]the study measured the marginal gap and determined the clinical acceptability of single castings invested in a phosphate-bonded investment with the use of conventional and accelerated methods. Forty –four individual stone casts were poured from impression made from a master die. Conventional and accelerated methods of investing and casting were followed in the fabrication. Each casting was seated on its respective stone dies and subjected to a constant load of 400g for 5 minutes. The weight was removed , and a spring-loaded caliper was used to maintain a constant seating pressure between the casting and stone die during microscopic measurements, it was recorded at X50 magnification on the perpendicular and on a 25-degree angle to the axial wall.

Measurements were made from crown margin to stone margin for marginal gap recordings. Marginal gaps were measured to the nearest micron on each casting at 4 predetermined sites. Even though marginal gaps for castings made with an accelerated technique showed no statistical difference when compared with a conventional casting group, it offers a cost effective and time saving method by which single unit castings for metal /ceramic crowns can be fabricated. They concluded from their investigations that the phosphate bonded investment selected for an accelerated casting technique produced single castings within 30 minutes with marginal gaps comparable to those of conventional methods.

Pallesen U, van Dijken JWV.(2000) [37] A study was conducted to evaluate the Cerec CAD/CAM inlays processed of two ceramics, half made of feldspathic and other of glass ceramic block. It was concluded that the CAD/CAM inlays processed of the two ceramics functioned well.

Ushiwata O and MoraesJVde (2000) [51]this study describes an innovative method for measuring the marginal discrepancies using a toolmakers microscope. The device that allowed fixation of specimens on a toolmaker's microscope with identical conditions according to three-dimensional positioning of specimens, measuring location, and seating force. This device can be used to measure the margins throughout the periphery.

Groten M, Axmann D, Dr rernat, Pr Obster L, and Weber H,(2000) [18]this study concluded that a minimum of 50 measurements are required for clinically relevant information about gap size regardless of whether the measurement sites are selected on random basis. It was of minor importance whether 50 measurements along the margin were randomly selected or recorded in distance of about 500 microns.

Renata Marques de Melo, DDS, Alessandro Caldas Travassos, DDS and MaximilianoPieroNeisser (2005) [41]this study evaluated the shear bond strength between a porcelain system and 4 alternative alloys. Shear bond strength evaluation of the interface formed by base metal alloys (Co-Cr, Ni-Cr) with a dental porcelain product revealed no statistically significant differences in bond strength of the 4 alloys and ceramic tested. They concluded from their investigations that the success of a metal restoration depends on strong adhesion between porcelain and alloy. The bond strength of the alloy, IPS, d.sign 20, was not different from the 3 other base metal alloys.

A.Bindl and W.H Mormann (2005) [6] conducted their study SEM and stated that the cerec in lab system has marginal and internal dimensions in accordance with the dimensions of the conventional heat pressing method.

Ramakrishna Venugopalan, Regina.L.W.Messer. (2005) [40] in this study they discussed about the effect of a micro carrier suspension cell system on polarization from Ni-Cr dental casting alloys. Nickel-based alloys have been in use since 1930 and there are concerns regarding the corrosion or degradation by- products of these alloys release into the surrounding tissue and their cytotoxicity to the tissue's normal function. The study showed that media with serum and antibiotics (complete media) induced a significantly higher corrosion rate (95% confidence level) for both material compared to the other test conditions.

Y.Kokubo, Y.Nagayama, M.Tsumita, C.Ohkubo, S.Fukushima and P.VultSteyern.(2005) [29]The clinical study concluded that the mean marginal gap was an acceptable 66.8µm, and the marginal gaps were the smallest with occlusal gaps were the largest. The In-Ceram coping fabricated using the GN-I system was a better alternative to the conventional method

AnnaPersson,MattsAndersson,DDS,PhD, AgnetaOden,MSc,PhD,DDS. (2006)[2] the purpose of this study was to determine the repeatability and relative accuracy of 2 dental surface digitization devices. A computer – aided design (CAD) technique was used for evaluation to calculate and present the deviations 3-dimensionally. Ten dies of teeth prepared for complete crowns were fabricated in pre sintered yttria- stabilized tetragonal zirconia (Y-TZP). The surface were digitized 3 times each with an optical or mechanical digitizer. The number of points in the clouds from each reading were calculated and used as the CAD reference model (CRM). In color – difference maps, the distribution of the discrepancies between the surfaces in the CRM and the 3-dimensional surface models was identified and located. In this study they concluded from their studies that the repeatability of the optical digitizer was comparable with the mechanical digitization device, and the relative accuracy was similar.

SiegbertWitkowski, MDT, CDT, FutoshiKomine, DDS, PhD, and Thomas gerds,PhD. (2006) [45] Studies conducted to evaluate the marginal accuracy and refinement time of titanium copings fabricated by 3 different CAD/CAM systems,pro 50(PRO),DCS,andEVE.Of the systems tested, DCS system performed the best with regard to marginal accuracy.

PenwadeLinkangwalmongkol, DDS, MS, Gerard J. Chiche, DDS, and Markus B.Blatz, DMD, PhD. (2007) [38] from their lab studies revealed that the porcelain butt margins had a better marginal fit than feather- edge metal margins.

Wazzan KAA, Nazzawi AAA (2007) [55] this In vitro study was to investigate the marginal accuracy and internal fit of complete cast crowns after and fixed partial dentures casted with pure titanium alloy. The study concluded that titanium alloy (Ti-6AL-4V) demonstrated less fit discrepancy than commercially pure Ti castings and single crown offered better fit than fixed partial denture and mid occlusal internal fit demonstrated greater gap discrepancy than axial internal fit.

Traini,T. Mangano,C. sammons, R.L.Mangano, F.Macchi, A.Piattelli. A(2008) [50] This work focuses on a titanium alloy implants incorporating a gradient of porosity, from the inner core to the outer surface, obtained by laser sintering of metal powder. Surface appearance, microstructure, composition, mechanical properties and fractography were evaluated. Methods: a selective laser sintering procedure using a Ti–6Al–4V alloy powder with a particle size of 1–10μm prepared all the specimens. The morphological and chemical analyses were performed by SEM and energy dispersive X-ray spectroscopy. In conclusion, laser metal sintering proved to be an efficient means of construction of dental implants with a functionally graded material, which is better adapted to the elastic properties of the bone. Such implants should minimize stress-shielding effects and improve long-term performance.

KatrinQuante, Klaus Ludwig, Matthias Kern,(2008) [27]investigated the marginal and internal fit of metal ceramic crowns using a silicone indicator paste. The results showed that the crowns produced with laser melting technology exhibit a marginal and internal accuracy that is comparable to conventional production procedures.

Hong Tzongyau, Chien Yu Hsu, Hui Lang Peng and ChihChaunpai (2008) [21]in this article on computer aided “ Framework Design For Digital Dentistry” which aimed in proposing a customizing dental framework design system to improve artificial teeth production. The author explains about scanning and how the registration and triangulation algorithms are used to reconstruct the scanned data to triangular solid model.

TolgaAkova, YurddanurUcar, AlperTukay, Mehmet CudiBalkaya, William A.Brantley (2008) [49]compared the shear bond strength of cast Ni-Cr and Co-Cr alloys and Laser sintered Co-Cr alloys to dental porcelain , they concluded that the new laser sintering technique for Co-Cr alloy appears promising for dental applications, but additional studies of properties of the laser sintered alloy and fit of the castings prepared by this new technique are needed before the acceptance into dental laboratory practice.

Gonzalo E, Dr Odont, Suarez MJ, Serrano B, Lozano FL(2009) [19] a In vitro study was conducted to compare changes in marginal fit of posterior fixed dental prosthesis of 3 zirconia systems manufactured using CAD / CAM technology and metal ceramic posterior fixed dental prostheses fabricated with the conventional lost was technique, before and after cementation. The study concluded that cementation did not cause a significant increase in the vertical marginal discrepancies of the fixed dental prostheses and that an internal space of 50μm provided a high precision of fit for the restorations.

YurdanurUcar,DDS, MS,PhD, TolgaAkova,DDS,PhD, Musa S.Akyil, DDS,PhD, and William A. Brantley, PhD. (2009) [56] conducted a study to compare the fit of the conventional Ni-Cr and Co-Cr alloy crowns with laser sintered Co-Cr alloy crowns using two techniques: 1. Weighing the light body addition silicone that simulated a cement material, and 2. Measuring the internal gap width on a die for longitudinally sectioned specimens. The light body silicone weight used to provide relative comparison for the fit of castings was relatively lighter for laser sintered Co-Cr alloys and there wasno significant differences were found among the 3 alloy groups evaluated for the internal gap width of sectioned crown specimens.

Jason E. Holden, Gary R.Goldstein,Hittleman, and Elizabeth A. Clarks (2009) [25] this In- Vitro study was to compare the marginal adaptation of a pressed ceramic material, when used with and without a metal porcelain butt margin. A master model was created by preparing a maxillary right central incisor typodont tooth with uniform 1.5mm circumferential shoulder with rounded internal line angle and 2mm incisal reduction. Die stone models were fabricated for 3 groups 1. traditional metal ceramic restoration (MCR), 2.

leucite-glass-pressed ceramic (PCR)and 3. Pressed to metal restoration (PTM). The crowns were seated with finger pressure, and a small (1x1mm sq) amount of composite resin was adapted to the margin away from the measurement area. The result demonstrated from their studies that the pressed to metal (PTM) restorations showed a smaller marginal opening than the metal ceramic restorations (MCR).

XiaoyongTian, Jens Gunster, JorgMelchr, Dichen Li, Jurgen G. Heinrich. (2009) [57]studied the effects of laser sintering and attained appropriate laser sintering parameters : laser power 50W, scan speed 85mm/s; and hatching space 0.6mm.It has also been stated that in the laser sintering process, lower laser energy density and higher hatching space will increase the final mechanical properties of the porcelain components.

Gareth Tomkinson ,Renishaw (2010) [16]This article explained about the functioning, method and discussion on the Laser PFM, the introduction of CAD/CAM for mainstream brought with it a new range of exiting features ; precision fit , reduced marginal adjustment and controlled material, consistent frameworks with no inclusions or casting defects. They emphasized on the procedure of Laser sintering ,(3D printing) , because it builds up each framework in a series of successive thin layer (0.02mm thick) , and it could replace the conventional lost wax technique.

MiliaAboutara, StephanieEschbach, Frank Bohlsen, Matthias Kern,(2011) [33]this In Vivo study was to evaluate the clinical outcome of posterior single-unit metal ceramic crowns fabricated using computer-aided design / computer- assisted manufacture laser-sinter technology. 60 restorations were fabricated using DMLS technology. A high – energy focused laser beam directly fused a localized region of a thin layer of a metal powder to build up the restoration gradually. A precious alloy (gold –platinum) and a base metal alloy (Co-Cr) were used for 29 and 31 restorations. The thickness of the metal copings was a minimum 0.35mm for base metal alloy and 0.5mm for the noble alloy. The thickness of the veneer restoration was a minimum 1.5mm occlusally and 0.8mm cervically. Follow- ups were performed annually. Over this period, the outcomes are comparable to that for conventional fabricated metal-ceramic crowns.

Seok Hwan Cho, DDS,MS, William W. Nagy, DDS, John t. Goodman DDS, Eric Solomon, DDS, PhD and Mari koike, DDS, PhD. (2012) [43]. This In Vivo study was to evaluate the effect of repeated firing cycles on the marginal discrepancy of veneered (layered) pressable ceramic anterior crowns with 2 different finish line configurations. 40 pressable ceramic single anterior complete crowns were fabrication from 2 systems with 2 finish line designs on epoxy resin dies. The measurements were made after pressing and after 5 veneer firing stages , wash first incisal second incisal characterization and glazing and correction. The change in vertical marginal discrepancy was measured with a light microscope at four locations facial (F),mesial (M), lingual(L), and distal (D),surfaces. The results showed no significant changes in the vertical marginal integrity related to ceramic type and marginal location and their interactions.

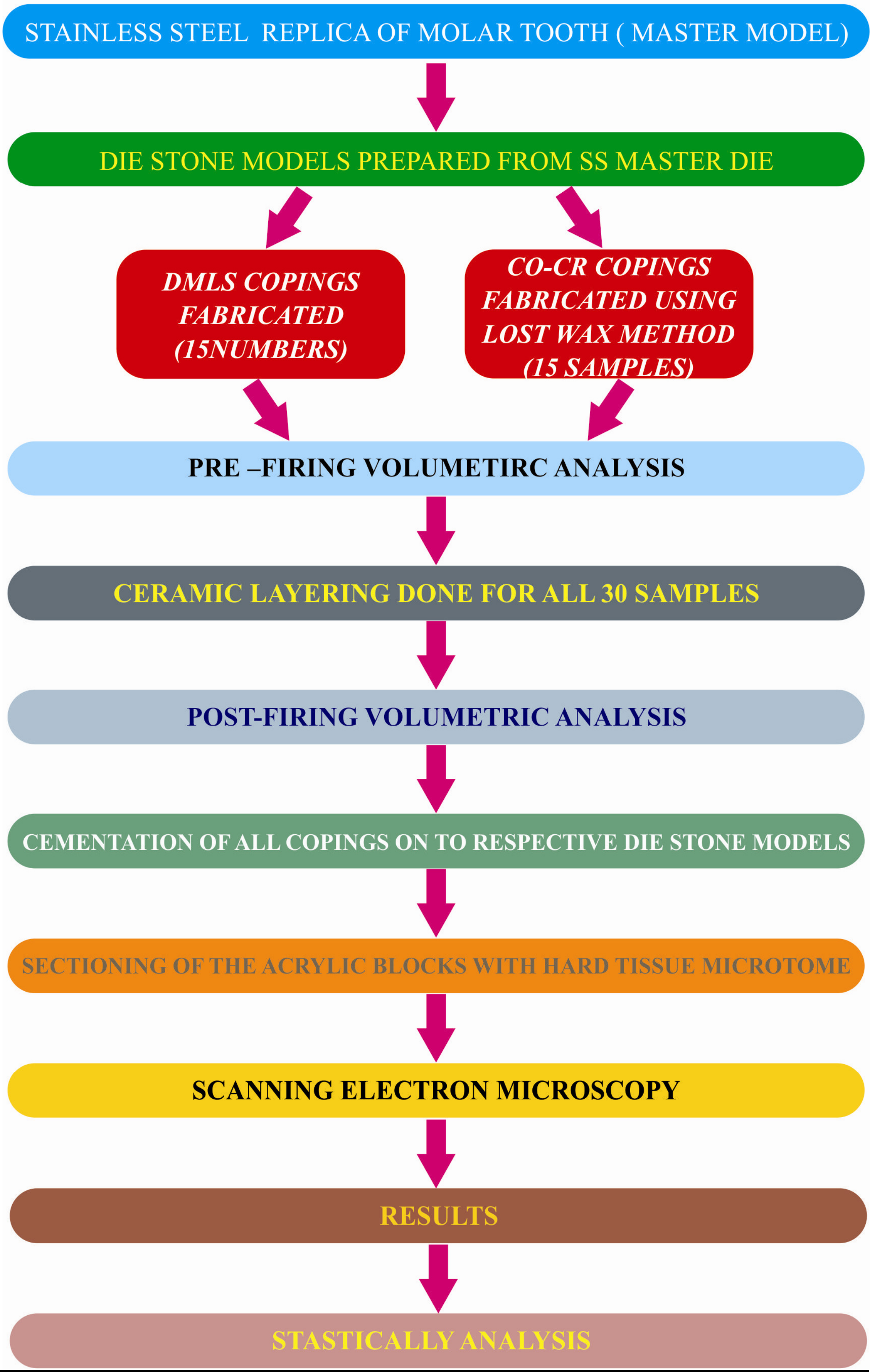
Juliana TerezaColpani, Marcia Borba, Alvaro Della Bona, (2013)[26], the main objective of this study was to measure the marginal and internal adaptation of different prosthetic crowns infrastructures (IS); to analysis two types of methodologies (replica and weight technique) used to evaluate the adaptation of indirect restoration. Ceramic (IS) were fabricated using CAD /CAM technology and slip-casting method and metal IS were produced by casting. For each group the adaptation was evaluated with the replica (RT) and weight technique (WT), using an impression material (low viscosity silicon) to simulate the luting agent. Cross section images of the silicon replica were obtained and analyzed with image J software to measure the low viscosity silicon layer thickness at pre- determined points. The silicon layer was also weighted. The result of all IS showed clinically acceptable values of marginal and internal adaptation.

BhaskaranEswaran ,Azhagarasan, N. Miglani, Saket, Illango,T, Krishna, G, Gajapathi.B (2013) [5] conducted a In Vitro study to compare marginal and internal gap of Co-Cr copings Fabricated from conventional wax pattern, 3D printed resin pattern and DMLS technique. Among the total 30 test samples 10 casts copings were made from inlay wax and 10 from 3D printed resin pattern, 10 copings were fabricated using the new DMLS technique. All the 30 samples were then cemented sequentially on stainless steel model using pressure-indicating paste and evaluated for marginal gap in 8 pre-determined reference areas. All copings were then removed and partially sectioned and cemented sequentially on same master model for evaluation of internal gap. The study concluded that DMLS technique had better marginal integrity.

Venkatesh,K. Nandini,V (2013) [53]This article discussed the process of laser sintering for making metal crowns and fixed partial dentures with a understanding of their pros and cons. Dental technology is undergoing advancements at a fast pace and technology is being imported from various other fields. One such imported technology is direct metal laser sintering technology for casting metal crowns.

Kim, Ki-Baek. Kim, Woong-Chul. Kim, Hae-Young. Kim, Ji-Hwan (2013) [28]This in vitro study aimed to evaluate and compare marginal fit of three-unit fixed dental prostheses (FDPs) fabricated using a newly developed direct metal laser sintering (DMLS) system with that of three-unit FDPs by a conventional lost wax technique (LW) method. Methods: Ten cobalt–chromium alloy three-unit FDPs using DMLS system and another ten nickel–chromium alloy FDPs using LW method were fabricated. Marginal fit was examined using a light-body silicone. After setting, the silicon film was cut into four parts and the thickness of silicon layer was measured at 160× magnification using a digital microscope to measure absolute marginal discrepancy (AMD), marginal gap (MG) and internal gap (IG). The marginal fit of the DMLS system appeared significantly inferior compared to that of the conventional LW method and slightly larger than the acceptable range.

FLOW CHART FOR METHODOLOGY



MATERIALS AND METHOD

Inclusion criteria:

1. The study was limited to lower posterior single tooth (molar 36, 46)
2. Dies prepared with proper records of margins, and dimensions were used in the study.

Exclusion criteria:

1. The impressions were discarded if any voids or dimension inaccuracy were present.
2. The sample was inspected for voids in the Die, and was discarded.
3. Casting defects, like marginal inaccuracy, voids in the finish lines and internal surfaces were discarded.

METHODOLOGY

The following methodology was adopted for the study:

1. **Fabrication of master model and samples**
   A. Preparation of stainless steel master model from computer numerical control (CNC) milling.
   B. Fabrication of stainless steel custom tray.
   C. Impression making of the master models to produce 30 samples.
   D. Preparation of the die stone models (30 samples).
   E. Preparation of 15 metal copings with lost-wax technique.
   F. Preparation of 15 metal copings with Direct metal laser sintering technique
   G. Ceramic layering for all 30 metal coping samples. (15 samples of lost-wax and 15 samples of DMLS)
   H. Cementation of all PFM coping on to respective die stone models.
   I. Cemented model assembly mounted with chemically cured acrylic material.
   J. Sectioning of the acrylic blocks performed using hard tissue microtome.

1. **<u>Evaluation of samples</u>**
   A. Volumetric analysis (internal gap) of the copings (pre firing)
   B. Volumetric analysis (internal gap)of the copings (post firing)
   C. Scanning electron microscopy for marginal gap measurement

MATERIALS USED FOR THE STUDY:

1. Stainless steel master model
2. Poly vinyl siloxane putty and light body impression material (Dentsply,Aquasil, putty soft Type0 /light body type IV, GERMANY)
3. Type IV die stone (Type IV, Ultrarock, Kalabhai, INDIA).
4. Auto-polymerizing acrylic resin material (DPI, Dental, INDIA)
5. Die hardener (Yeti, Germany)
6. Die spacer (Yeti, Germany)
7. Die Lubricant (Yeti, Germany)
8. Dip wax (Yeti, Germany)
9. Margin wax (Yeti, Germany)
10. Sprue wax (Delta labs, Chennai, India)
11. Surfactant spray (aurofilm, Bego ,Germany)
12. Phosphate bonded investment (Cobavest , Yeti, Germany)
13. Base metal CO-Cr (4 All, Ivoclar vivadent)
14. Aluminium oxide powder (110µm), (Delta labs , Chennai, India)
15. Tungsten carbide burs (Edenta, Switzerland)
16. Dental ceramics (IPS d Di Sign i Sign, Ivocalr Vivadent)
17. Silicone pressure indicating paste (Fit checker II,GC, Japan)
18. Glass ionomer cement (Type I, GC Fuji, Japan)

ARMAMENTARIUM USED FOR THE STUDY:

1. Vacuum powder mixer (Silfradent ,Italy)
2. PKT instruments.(Dispondent , India)
3. Burnout furnace (Delta labs, Chennai, India)
4. Induction casting machine (Fornax, Bego ,Germany)
5. Sandblaster (Delta labs, Chennai, India)
6. Alloy grinder (Ray and Foster, USA)
7. LAVA ST Scanner (3M ESPE, USA)
8. Direct Metal Laser Sintering Machine (EOSINT M 270)
9. Electronic weighing Machine(Schimadzu, Japan)
10. Hard tissue microtome (IsoMet 5000 linear precision saw , Buelher, Germany)
11. Plasma gold sputtering machine (Quorum, Q150 RS)
12. Scanning electron microscope (Sigma V, Carl Zeiss, Munich, Germany)

I. FABRICATION OF SAMPLES:

1. Fabrication of Master model:

A master model of the posterior tooth, of 6mm height, and 5mm diameter with a 360-degree chamfer preparation and16-degree total occlusal convergence (TOC) was fabricated as per the standardization derived from The Dental clinics of north America[48] and Shillingburg HT, et al[44]. The master model was fabricated in stainless steel by computer numerical control milling machine (CNC Milling). (Fig.1)

2. Fabrication of custom tray:

To standardize the impression of the master model a custom tray was fabricated in stainless steel (Fig.2).A cylindrical hollow tube with a diameter of 3cm, length of 2.5cm, with a detachable base and a removable lid was prepared.18 holes were made on the outer surface of the cylindrical shaped custom tray for mechanical retention of the impression material. Holes were prepared in the lid and base of the tray, which acted as vents for the excess impression material to flow. 30 Poly vinyl siloxane impressions (Dentsply, Aquasil, putty soft/light body, GERMANY) (Fig 3) were made in two-stage technique to produce the samples.

3. Preparation of Die stone models

An elastomeric impression (DENTSPLY,Aquasil, putty soft/light body, GERMANY) of the custom-made stainless steel master model was made with addition silicone (Fig.4) using two-stage technique. Thirty separate impressions were made to prepare 30 working models. Surfactant was sprayed into mould space of the impression before the die stone was poured. Type IV dental stone (Kalrock, Kalabhai,INDIA) (Fig 5) was mixed as per the manufacturer recommendation and poured into the mold using a mechanical vibrator (Fig 6). The working models were grouped as follows

1. Group 1 (G1-LW) Conventional lost wax technique (15 samples). (Fig 7)
2. Group 2 (G2-DMLS) Direct metal laser sintering (15 samples). (Fig 7)

4. Fabrication of cast Co-Cr copings with inlay casting wax pattern (G1):

a) Preparation of wax patterns.

Group I (G1-LW) models were coated with one layer of Die Hardener (Yeti Dental, Germany) and 2 layers of Die spacer (YETI DENTAL, Germany) (Fig 8) Each layer was of approximately 15µm with a total thickness of 30µm.(Fig 9) . The die spacer was applied 0.5mm short of their cervical margins. A wax pattern of 0.3 to 0.5 mm thickness was made by dipping the model in a wax pot at a temperature of 98 degree centigrade.

Excess wax at the margins were cut and removed. Finish line was refined with cervical wax (YETI DENTAL, Germany) (Fig 10). Patterns were invested, cast and finished following standard casting procedure.

b) Sprue former attachment for the inlay casting wax patterns:

All the 15 wax patterns were connected to the sprue former (YETI DENTAL, Germany), of 3mm (Fig.11). The open arms were connected to the base of the crucible former. (Fig 12)

c) Investing procedure for the inlay casing wax patterns:

All the wax patterns were invested using graphite free phosphate bonded investment material (Cobavest , Yeti, Germany). A 6mm distance was provided between the margin of coping and top of the ring (Siliring, Delta, India) (Fig 13). As per manufactures' recommendation, 160 gm of phosphate-bonded investment requires 30 ml of colloidal silica mixed with 8ml of distilled water in ratio of 75:25 respectively. The patterns along with the sprue were treated with surfactant spray prior to investment. The investment material powder and liquid were first hand mixed until the entire material was wetted thoroughly followed by vacuum mixing (Tornado, Silfradent, Italy) (Fig 14) for 20 seconds. Siliring was positioned on the crucible former and patterns were painted with a thin layer of investment using a small paintbrush (Fig 16). Reminder of the investment was vibrated into the ring. The invested patterns were allowed to bench set for 20 minutes.

d) Burn out procedure for inlay casting wax patterns:

After 20 minutes bench time, the set investment mold was placed in the burnout furnace (Delta labs, Chennai, India) (Fig17). Burn out of the wax patterns was done using a programmed preheating technique. The investment mold was placed in the furnace such that the crucible end was in contact with the floor of the furnace for the escape of melting wax. The investment was kept in a furnace at room temperature and the furnace was brought to 200°C and held at this temperature for 30 minutes. Most of the wax was by then eliminated. The temperature was increased gradually to 650°C and later to the final burn out temperature of 950°C continuously at the rate of 8 degree C/min. This temperature was held for 45 minutes. The investment mold was reversed later near the end of the burn out cycle with the space hole facing upward to enable the escape of the entrapped gases and allow oxygen contact to ensure complete burnout of the wax patterns and allow mold expansion.

e) Casting procedure for wax patterns:

Casting was accomplished with a Co-Cr (Cobalt (Co) 66.62, Chrome (Cr) 28.26, Molybdenum (Mo) 5.5,Tungsten (W) – 5, Silicon (Si) – 1,2,Cerium (Ce) – 0,3,Other elements (Mn, Si, Fe) <1, Other elements (Nb, Fe, N) – <1)alloy melted in an induction-casting machine (Fornex ,Bego, Germany) (Fig18). The casting procedure was performed quickly to prevent heat loss resulting in the thermal contraction of the mold. The Co-Cr alloy was heated sufficiently till the alloy ingot turned to molten state and the crucible was released and centrifugal force ensured the completion of the casting procedure (Fig 19). This procedure was repeated for all 15 patterns for lost wax technique.

f) Divesting and finishing of cast copings obtained from inlay casting wax patterns:

Following casting the hot casting ring was bench cooled to room temperature. Divesting was done to retrieve the cast copings from the investment. Care was employed to prevent damage to the margins. Adherent investment was removed from the casting by sandblasting with 110µm alumina at 80psi pressure (Fig 21). The sprue was cut with the help of a thin carborundum disc and the area of its attachment was recontoured. The internal surface of the copings were inspected under magnification and relieved of all nodules with a round carbide bur and steam cleaned. This procedure was repeated for all the 15 Co-Cr cast copings and the obtained metal copings were labeled as group 1(G-1 LW)-test samples. (Fig.22)

5. Fabrication of Co-Cr copings with direct metal laser sintering- (G2):

The 15 samples of type IV die stone was scanned using Lava ST scanner and the registration and algorithms were used to reconstruct the scanned data into a triangular solid model (Fig 23). The marginal location and the spacer thickness adaptation were done by, D 700 scanner. Then the non-uniform offsetting and shelling algorithm was proposed to create the coping shell model with a uniform thickness of 0.5 mm. The STL data thus obtained was forwarded to CAM bridge, which is a professional software for automatic part placement, orientation and identification (Fig 24). From here the data was forwarded to building chamber (An EOSINT M 280 direct metal laser-sintering) where infrared laser beam was used to fuse the (Co-Cr) powder, layer by layer to produce the solid object (Fig 25). Production began once a layer of powder was spread across the build platform, which then evenly spreads with a powder-leveling roller. The laser beam scans the powder surface, heats the particles and fuses them. After the first layer solidifies the built platform moves another layer of powder, which again gets sintered by the laser beam. The process was repeated until the copings were completed. After completion of these procedures 15 copings were obtained which was sand blasted with 110µm aluminum oxide powder, steam cleaned and labeled as group 2 (G2 DMLS) test samples (Fig 26).

6. Measurement of internal gap dimension using silicon fit checker (pre-firing metal copings)

To evaluate and compare the gap dimension between the metal copings and the stainless steel master model(15 samples of lost wax and 15 samples of DMLS), the marginal and internal openings were measured by using a white silicone pressure indicator paste (Fit Checker, GC, Japan) (Fig 27). Each metal coping was cemented on the stainless steel master model with a white silicone pressure indicator paste (Fit checker II, GC, Japan).The separating fluid was sprayed, before the cementation of each coping to lubricate the stainless steel master model. After mixing equal amounts of base and catalyst, the white silicon indicator paste (Fit checker II, GC,Japan)was placed inside each crown, simulating the clinical application of a luting agent. Metal copings were then seated on the master model using finger pressure for 2 minutes until the pressure indicating paste set (Fig 28). Following the removal of excess un-polymerized fit checker material at the margin, finger pressure was applied again for 1 minute. The excess material was removed using a size 12 Bard Parker blade. After polymerization of the silicone pressure indicator paste (Fit checker II,GC, Japan) metal copings were removed from the master model (Fig 29).The silicon coping formed in between the metal coping and stainless steel master model was removed carefully and was weighed using an Electronic analytical weighing machine (Schimadzu, Japan) (Fig 30). This silicon copings acts as the replica of the luting cement space to evaluate the gap dimension prior to ceramic firing. The same operator performed all the weighing measurements. The measurement values were in micrograms (µg) (Fig 31,32)

7. Ceramic firing stage

The ceramic layering were done using a ceramic furnace (Programat P 300) (Fig.33). All metal copings were degassed according to the manufacturers' recommendations. After degassing the metal copings were cooled in open air. The same cooling method was followed for all subsequent firing cycles (Fig 34). The opaque firing procedure was done in two stages: opaque and body applications. Maximum care was taken to produce an even opaque layer that had a final baked thickness of approximately 0.3mm. Following the opaque layer, the copings were layered with body porcelain and maximum care was give to make the thickness to 1mm (Fig 35- 37). Ivoclar IPS porcelain (Di-Sign, Ivoclar, Schaan, Liechtenstein) was used for all porcelain application according to the manufacturers' recommendations.

8. Measurement of internal gap dimension using silicone fit checker (post-firing metal ceramic copings)

The same procedure done to measure the internal gap dimensions for pre-firing coping were followed (Fig 38). Each metal ceramic coping was cemented on the stainless steel master model with a white silicone pressure indicator paste (Fit checker II, GC, Japan).The separating fluid was sprayed, before the cementation of each coping to lubricate the stainless steel master model. After mixing equal amounts of base and catalyst, the white silicone indicator paste (Fit checker II, GC, Japan) was placed inside each crown, simulating the clinical application of a luting agent. Metal ceramic copings were then seated on the master model using finger pressure for 2 minutes until the pressure indicating paste set. Following the removal of excess un-polymerized fit checker material at the margin, finger pressure was applied again for 1 minute. The excess material was removed using a size 12

Bard Parker blade. After polymerization of the silicon pressure indicator paste (Fit checker II, GC, Japan) metal ceramic copings were removed from the master model (Fig 39).The silicon coping formed in between the metal ceramic coping and stainless steel master model was removed carefully and weighed using the same Electronic analytical weighing machine (Schimadzu, Japan) and same operator performed all the weighing measurements. (Fig 40, 41)

9. Procedure for cementation of the copings:

All the test samples (30 numbers) were tried on the respective die stone models, and inspected before cementation procedures. A type I glass ionomer cement (GC Fuji, Japan) was used to lute the coping on die stone models, the mix was done according to the manufactures instruction. The excess cement was removed carefully and immediately without damaging the margins of the die stone models.

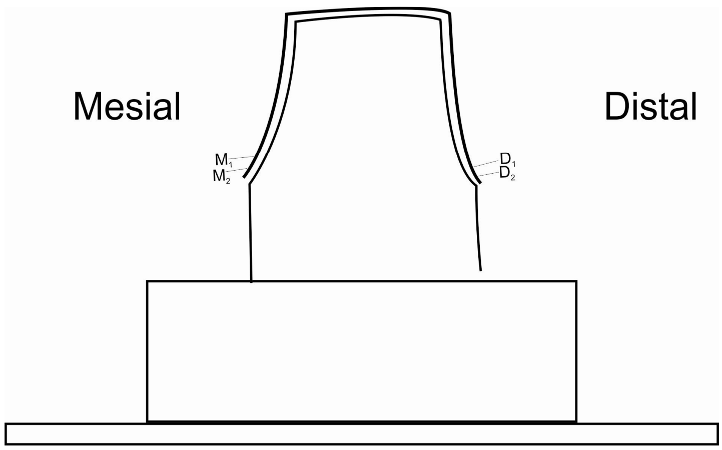
10. Fabrication of acrylic blocks:

Following cementation the entire assembly was cleaned and placed in a 2cm x 2cm cube acrylic box. The internal surface of the box was coated with separating medium. All the specimens were embedded in auto-polymerizing acrylic resin (DPI, India) (Fig 42) for stabilizing before the sectioning procedure. After curing, the blocks were removed from the box, steam cleaned and trimmed. These models were sectioned longitudinally in a mesio-distal direction using a electronically controlled hard tissue diamond saw (IsoMet 5000 linear presison saw , Buelher, Germany) (Fig 43). The sectioning was done at 2700 rpm. The half of the acrylic block not left in the saw device was used to analysis the marginal discrepancy (Fig 44). The cut sections were later used for a scanning electron microscopy study (Sigma V, Carl Zeiss, Munich, Germany).

11. Measurement of vertical marginal gap using scanning electron microscope:

The samples were sputtered with gold for 4 minutes (Quorum, Q150 RS) (Fig 46). The marginal and internal gap width was measured with a scanning electron microscope

(Sigma V, Carl Zeiss, Munich, Germany) (Fig.49) at 180-220X magnifications using the Particle measure system. The length of the calibrated electronic measuring bar of this system is adjusted to the width of the gap and provides the actual distance in microns, at that particular spot taking the actual magnification factor into account. The marginal width measurements were taken one-dimensionally across the gap filled with the adhesive luting material, which had been trimmed to the level with both the margins of the coping and the preparation. Four measuring locations were chosen exactly in meso- distal region(Fig 51,52). The measurements were done in pre-determined locations 50μm between two points (M1-M2, or D1-D2). The marginal gap was measured in (μm).



Schematic Representation of Areas to be Measured for Marginal Gap

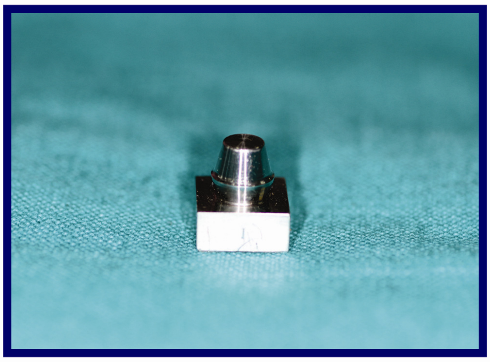


Fig:1 Stainless Steel Master Model

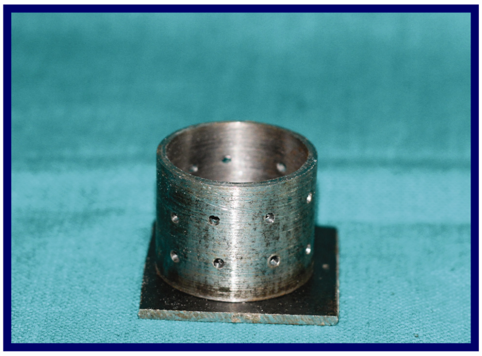


Fig:2 Stainless Steel Custom Tray

Fig:3 Polyvinyl Siloxane Putty and Light Body Impression Material

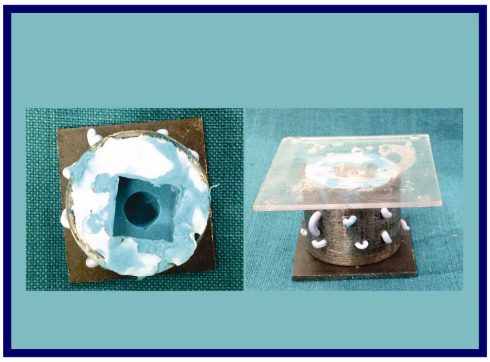


Fig:4 Impression of Master Model (two - stage technique)

Fig:5 Type IV Die Stone

Fig:6 Impression Poured With Type IV Die Stone Using a Mechnical Vibrator

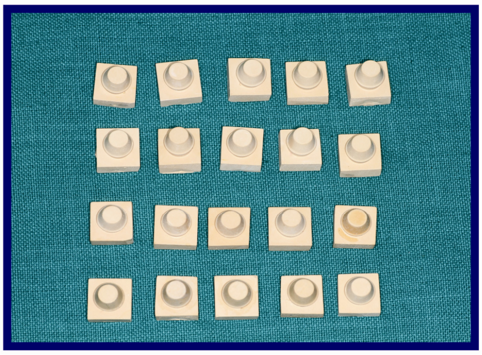


Fig:7 Samples Prepared From Type IV Die Stone

Fig:8 Die Hardener, Die Lubricant, Die Spacer, Dipping Wax, Wax Heater

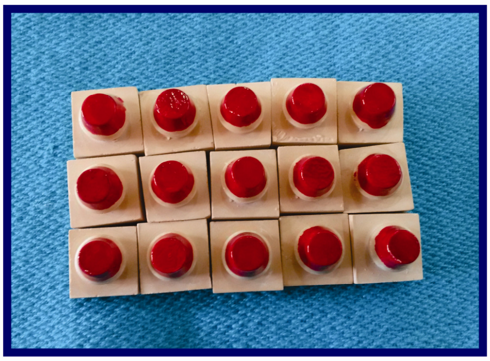


Fig:9 Dies Coated With Spacer

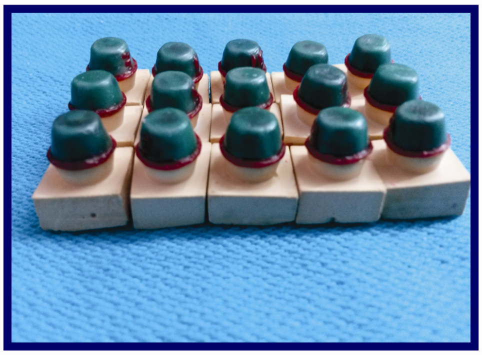


Fig:10 Prepared Wax Patterns On Respective Dies

Fig:11Wax Patterns Attached to Sprue Former

Fig:12 Wax Patterns Attached to Crucible Former

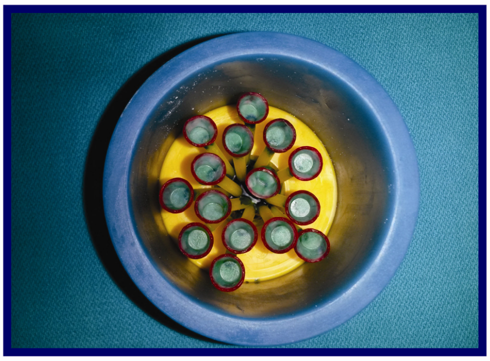


Fig:13 Wax Patterns Placed Inside Siliring

Fig:14 Vacuum Mixer

Fig:15 Phosphate Bonded Investment, Alloy (Co-Cr-Alloy Pellets), Siliring

Fig:16 Invested Wax Pattern

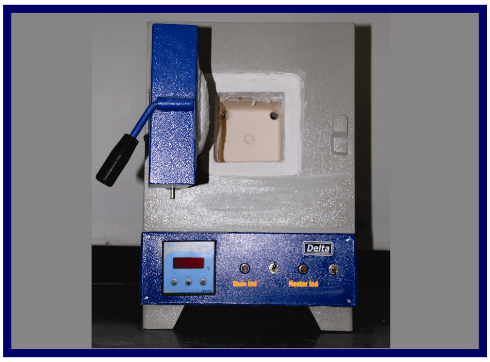


Fig:17 Burnout Furnace

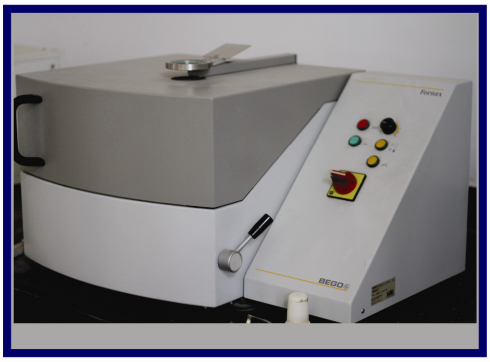


Fig:18 Induction-Casting Machine

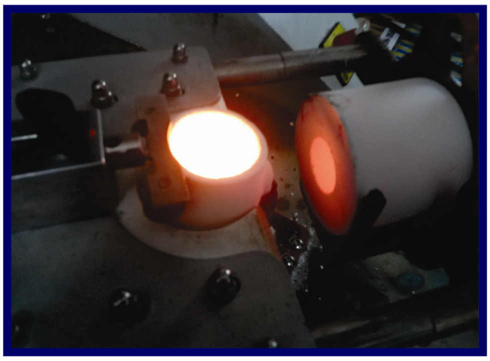


Fig:19 Casting Procedure

Fig:20 Investment With Casting Button

Fig:21 Devested Castings

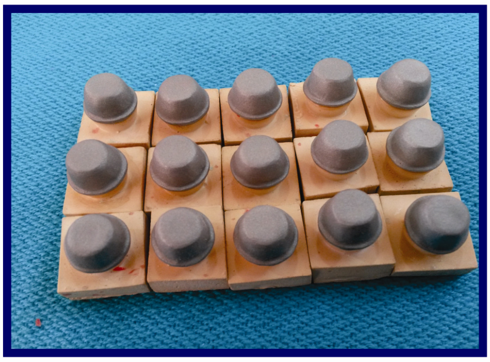


Fig:22 Finished Metal Copings

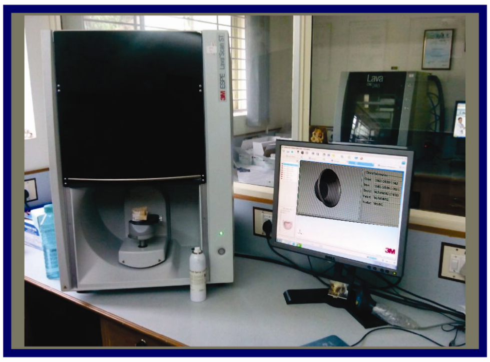


Fig:23 LAVA ST Scanner (D700)

Fig:24 Virtual Copings

Fig:25 Direct Metal Laser Sintering Machine
(An EOSINT M 280)

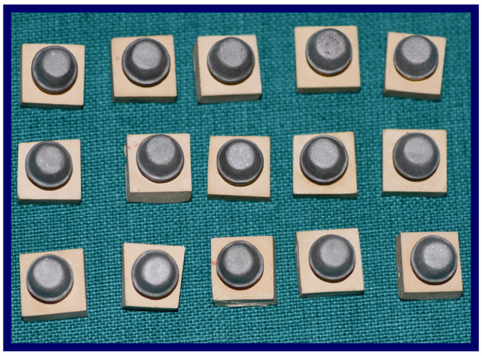


Fig:26 Copings Prepared From Direct Metal Laser Sintering

Fig:27 Pressure Indicating Paste
(Fit Checker, GC, Japan)

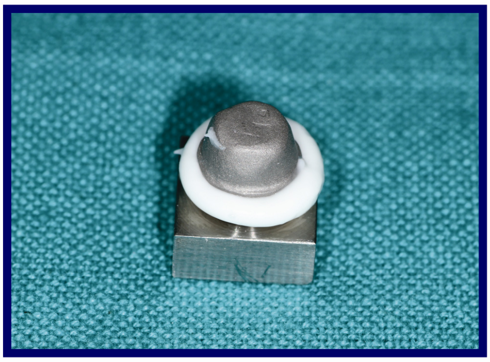


Fig:28 Copings With Pressure Indicating Paste on Stainless Steel Master Model

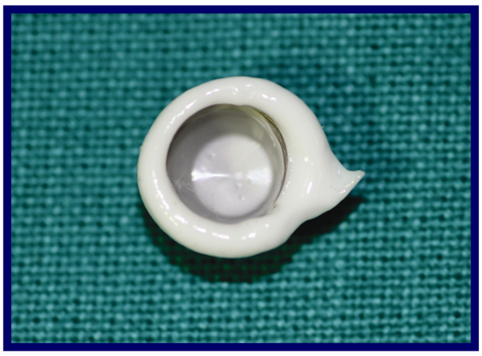


Fig:29 Internal Surface of The Pre-firing Metal Coping With Pressure Indicating Paste

Fig:30 Electronic Analytical Weighing Machine
(Schimadzu, Japan)

Fig:31Pre-firing Silicone Copings (G1-LW)

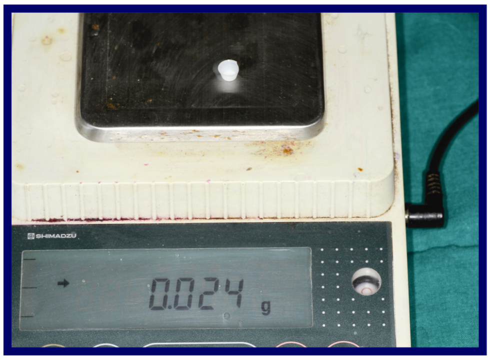


Fig:32 Pre-firing Silicone Copings (G2-DMLS)

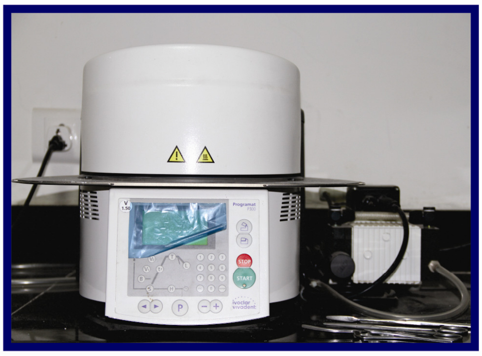


Fig:33 Ceramic Furnace (Programat P300)

Fig:34 Metal Copings (Degassing)

Fig:35 Ceramic Layering Materials
(IPS d.SIGN, Ivoclar Vivadent)

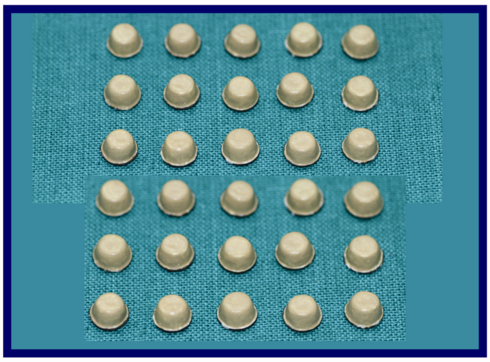


Fig:36 Metal Copings (First Opaque Layer)

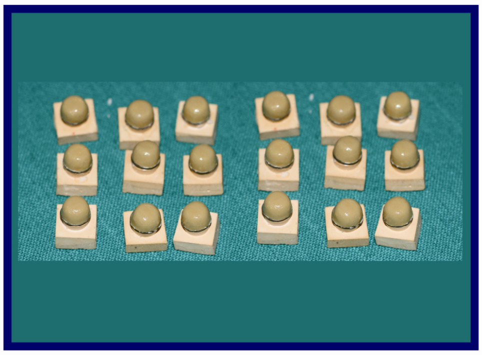


Fig:37 Metal Ceramic Copings

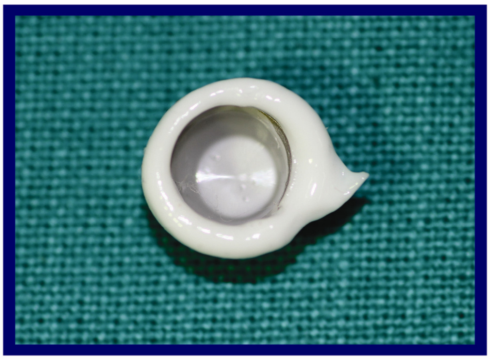


Fig:38 Internal Surface of The Post-firing Metal Coping With Pressure Indicating Paste


Fig:39 Silicone Copings

Fig:40 Post-firing Silicone Copings (G1-LW)

Fig:41 Post-firing Silicone Copings (G2-DMLS)

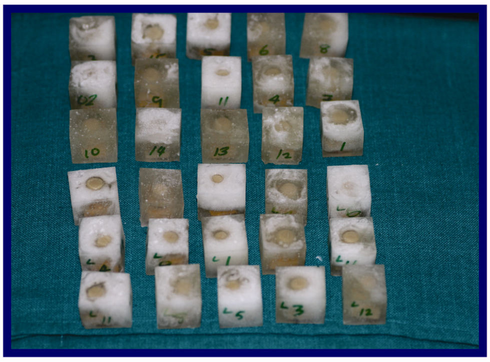


Fig:42 Acrylic Resin Blocks

Fig:43 Hard Tissue Microtome (IsoMet 5000 Linear Presison Saw, Buelher, Germany)

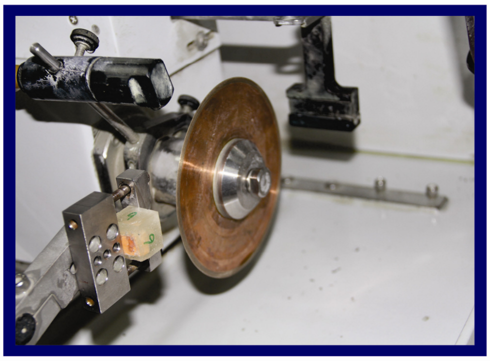


Fig:44 Specimen Mounted On Hard Tissue Microtome

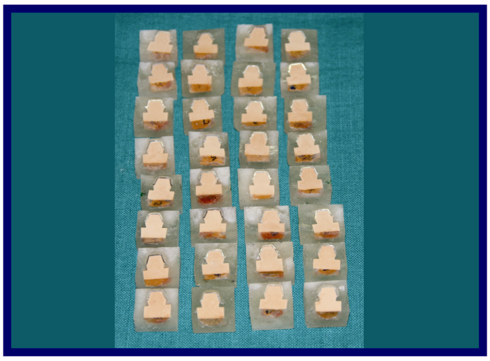


Fig:45 Sectioned Acrylic Blocks

Fig:46 Plasma Gold Sputtering Machine (Quorum, Q150 RS)

Fig:47 Specimen Coated With Plasma Gold

Fig:48 Specimen Mounted On Aluminium Stub

Fig:49 Scanning Electron Microscope (Sigma V, Carl Zeiss, Munich, Germany)

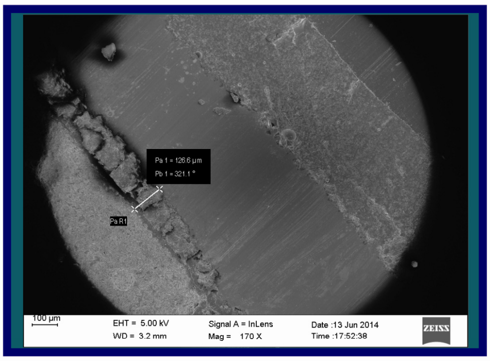


Fig:50 Scanning Electron Microscope Picture (G1-LW)

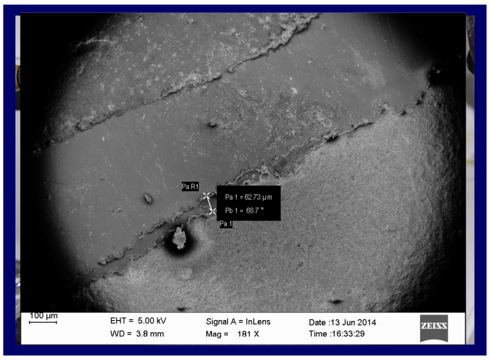


Fig:51Scanning Electron Microscope Picture (DMLS)

RESULTS

An in vitro study was conducted to evaluate the internal fit of conventional lost-wax technique with that of Direct metal laser sintered crowns. The conventional Lost-wax metal copings were fabricated in Co-Cr. The comparison was made between pre and post ceramic firing cycles.

Group 1: Test samples obtained from Lost wax (G1.LW)

Group 2: Test samples obtained from DMLS technique (G2.DMLS)

The results of each test were tabulated, and subjected to statistical analysis and the inference were shown in the following:

Statistical Analysis:

The data collected was entered in the excel spreadsheet and subjected to Statistical Analysis using SPSS version 17.0. Both descriptive and inferential statistics were used.

Descriptive statistics:

Descriptive statistics like mean, standard deviation, standard error of mean were calculated for both the weight of fit checker and SEM discrepancy between coping and margin.

Inferential statistics:

1. To compare the statistical difference between mean fit checker weight among two groups Unpaired student 't" test was used.

2. To compare the statistical difference between mean fit checker weight among the pre and post firing in each group paired student 't" test was used.

3. To compare the statistical difference between mean SEM discrepancy between coping and margin among two groups Unpaired student 't" test was used.

P value was fixed at 5% and any value below it was considered significant.

Note in tables:

* - Statistically significant.

** - Highly statistically significant.

*** - Very highly statistically significant.

Table 1. The weight (Values in µg) of fit checker used in DMLS method before and after firing with ceramic.

S.No	Prefiring	Postfiring
1	0.023	0.025
2	0.024	0.027
3	0.027	0.03
4	0.025	0.028
5	0.024	0.027
6	0.023	0.026
7	0.022	0.025
8	0.024	0.027
9	0.021	0.024
10	0.023	0.026
11	0.025	0.027
12	0.024	0.026
13	0.023	0.025
14	0.024	0.027
15	0.021	0.024

GRAPH 1

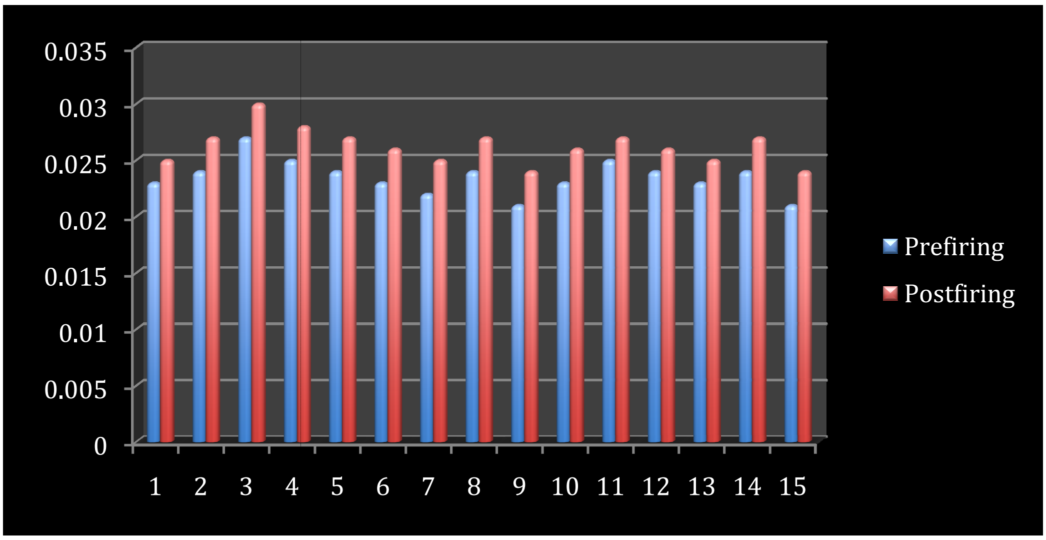


Table 2. Mean and Standard deviation of DMLS coping

MLS	Mean	Std. Deviation	Std. Error Mean	t	Sig.
Prefiring	.023533	.0015523	.0004008	-23.127	.000***
Postfiring	.026267	.0015796	.0004079		

GRAPH 2

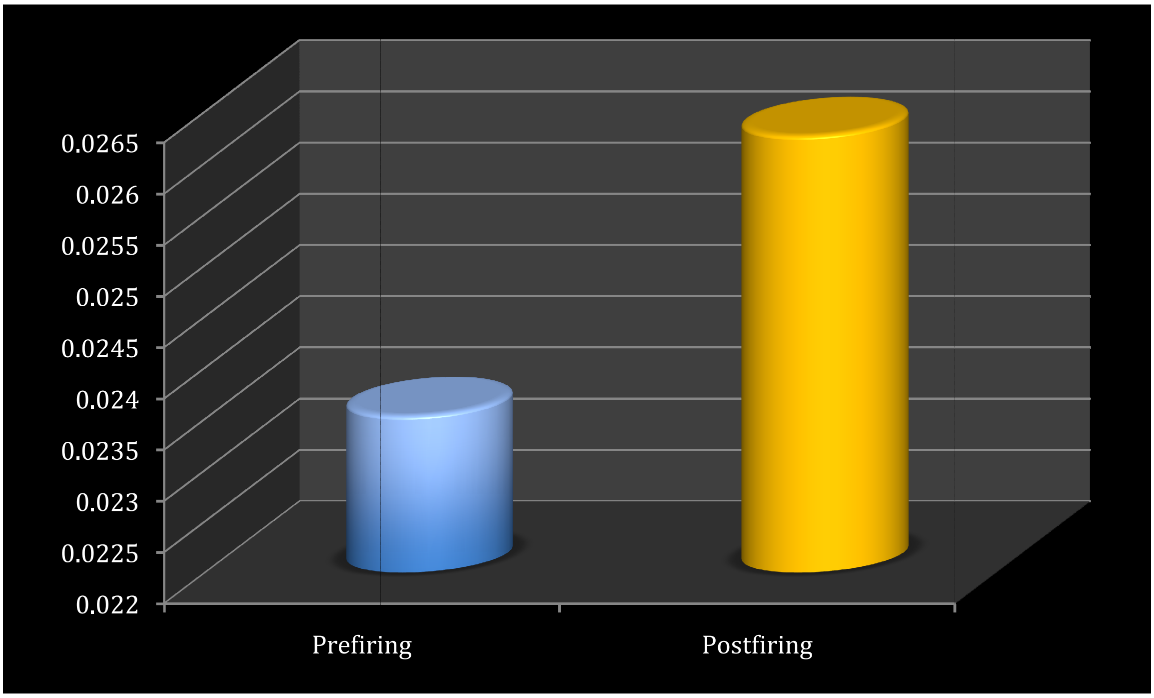


Table 3. The weight (Values in µg) of fit checker used in LW method before and after firing with ceramic.

S.No	Prefiring	Postfiring
1	0.031	0.034
2	0.033	0.037
3	0.029	0.033
4	0.031	0.034
5	0.04	0.044
6	0.041	0.044
7	0.038	0.041
8	0.033	0.037
9	0.032	0.037
10	0.038	0.042
11	0.038	0.041
12	0.033	0.037
13	0.032	0.037
14	0.033	0.037
15	0.029	0.033

GRAPH 3

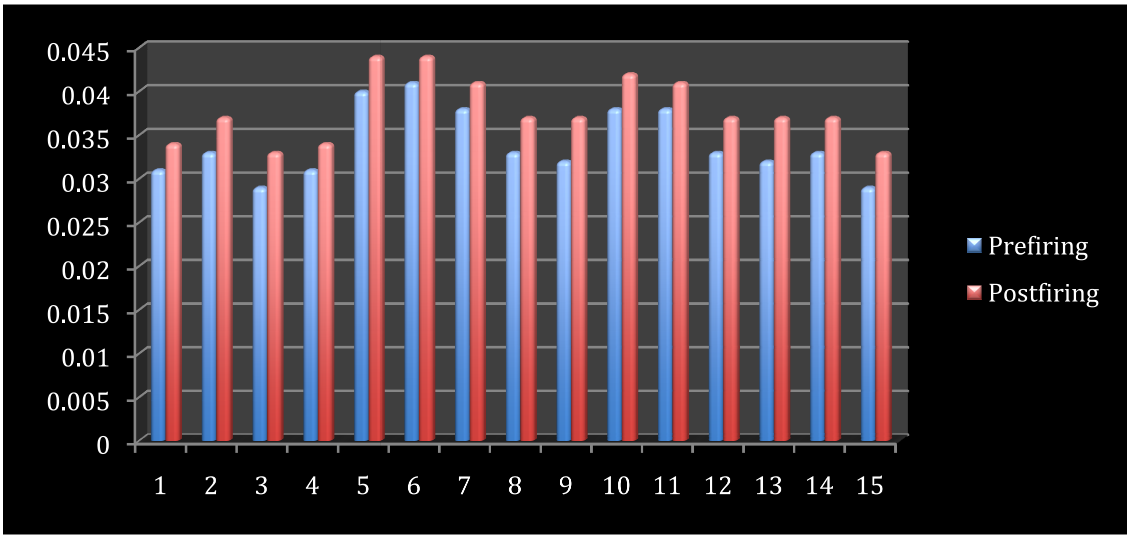


Table 4. The weight (Values in μg) of fit checker used in LW specimen before and after firing with ceramic.

LW	Mean	Std. Deviation	Std. Error Mean	t	Sig.
Prefiring	.034067	.0038999	.0010070	-21.767	.000***
Postfiring	.037867	.0037200	.0009605		

GRAPH 4

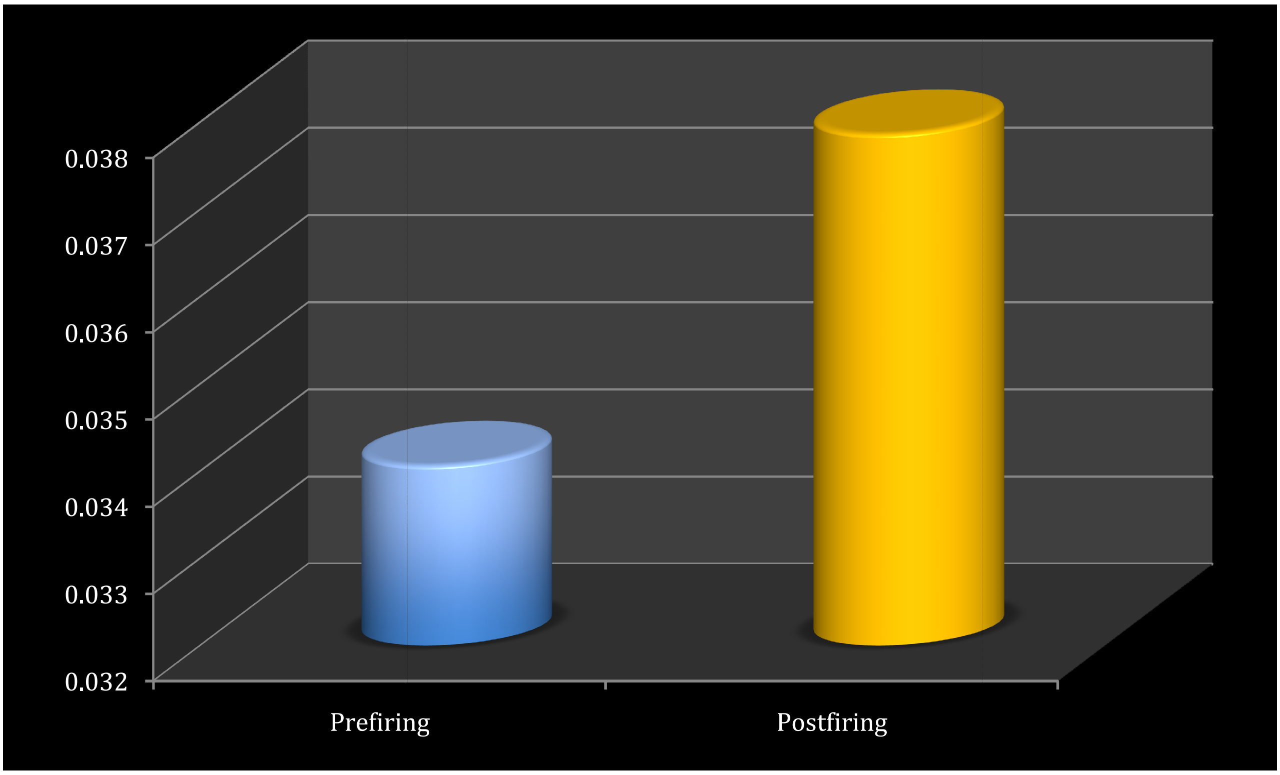


Table 5. Comparison of DMLS & LW (Pre-firing)

Parameter	Group	Mean	Std. Deviation	Std. Error Mean	t	Sig.
Prefiring	MLS	.023533	.0015523	.0004008	-9.719	.000***
	LW	.034067	.0038999	.0010070		

GRAPH 5

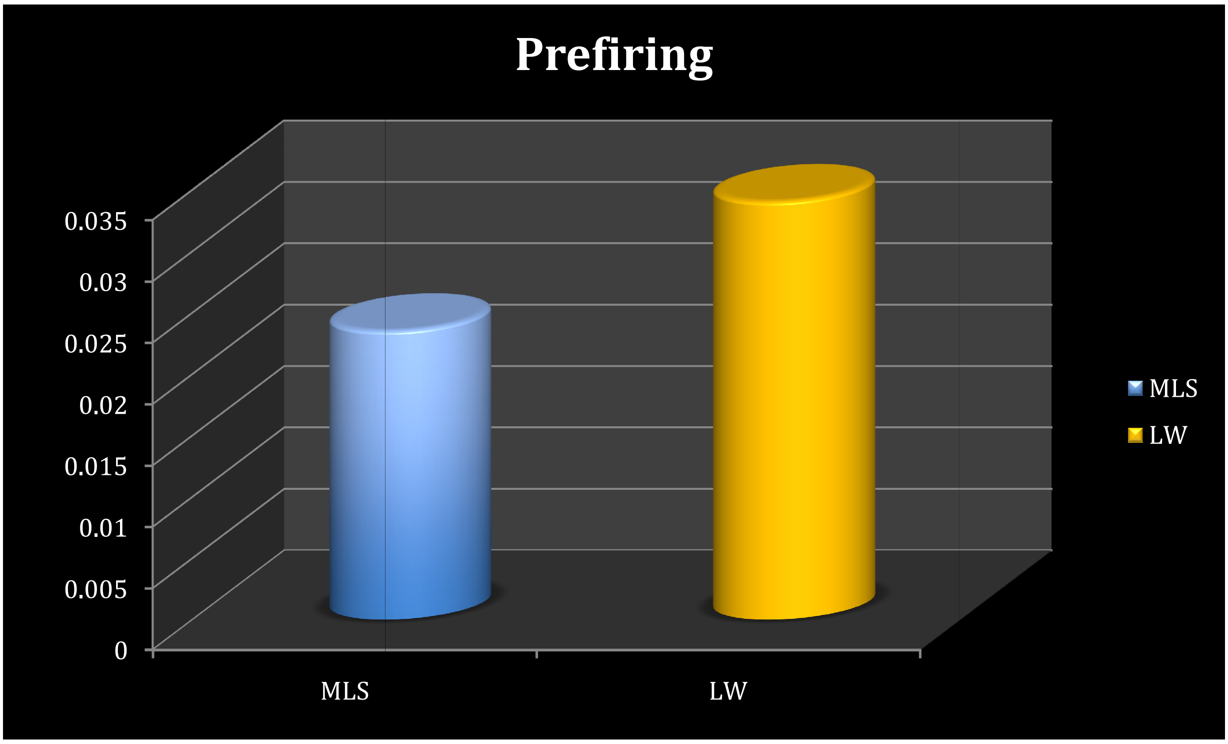


Table 6. Comparison of DMLS & LW (Post-firing)

Parameter	Group	Mean	Std. Deviation	Std. Error Mean	t	Sig.
Post firing	MLS	.026267	.0015796	.0004079	-11.116	.000***
	LW	.037867	.0037200	.0009605		

GRAPH 6

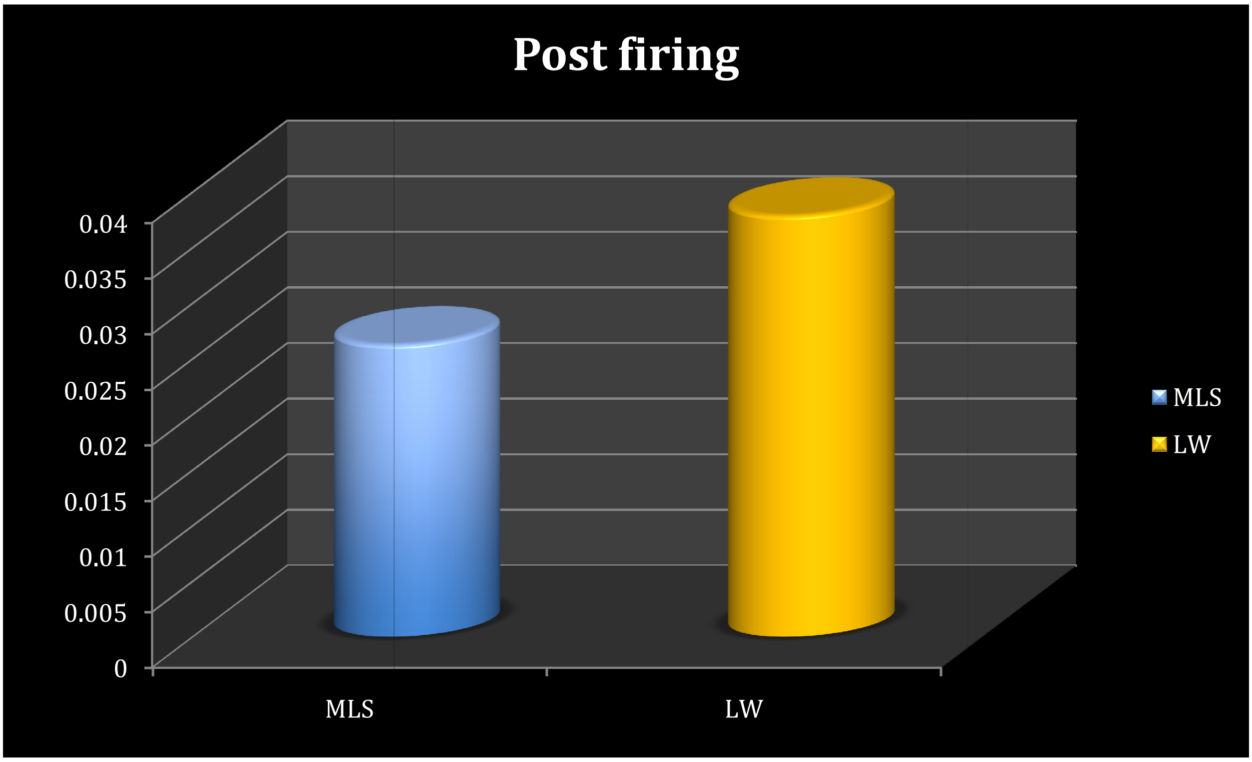


Table 7. Master table showing data entry of SEM images of the marginal discrepancy between coping and the die stone preparation in MLS method at two different points on the mesial and distal side

S.No	M1	M2	D1	D2
1	0.038	0.035	0.039	0.035
2	0.052	0.048	0.049	0.043
3	0.062	0.063	0.047	0.053
4	0.043	0.042	0.047	0.049
5	0.053	0.056	0.063	0.067
6	0.038	0.043	0.032	0.038
7	0.043	0.039	0.053	0.043
8	0.049	0.056	0.034	0.043
9	0.062	0.063	0.047	0.053
10	0.038	0.035	0.052	0.048
11	0.043	0.042	0.047	0.035
12	0.48	0.042	0.049	0.052
13	0.053	0.043	0.043	0.042
14	0.052	0.043	0.052	0.063
15	0.038	0.043	0.038	0.043

GRAPH 7

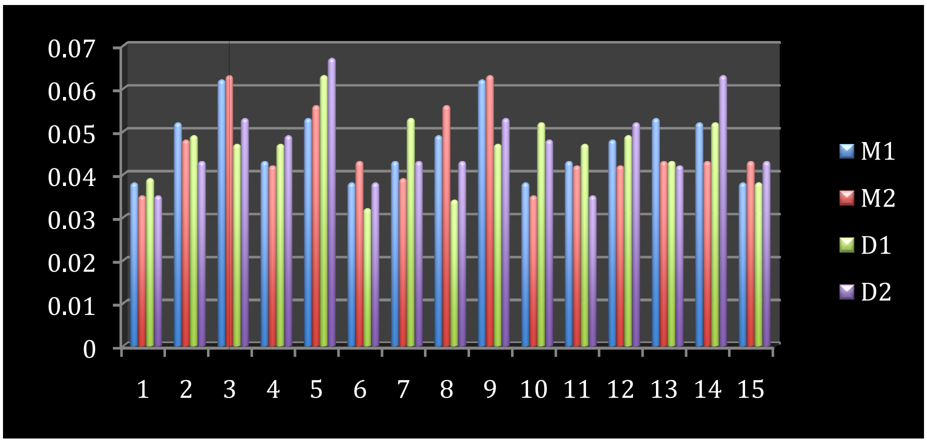


Table8. Shows the statistical significance between the marginal discrepancy of the coping with die stone model at two different points in the mesial side using DMLS method of fabricating the coping with SEM analysis. It was found that there was no statistically significant difference found between the two sites in the mesial side with p>0.05

MLS	Mean	Std. Deviation	Std. Error Mean	t	Sig.
M1	.0762667	.11199137	.02891605	1.031	.320^{NS}
M2	.0462000	.00908845	.00234663		

GRAPH 8

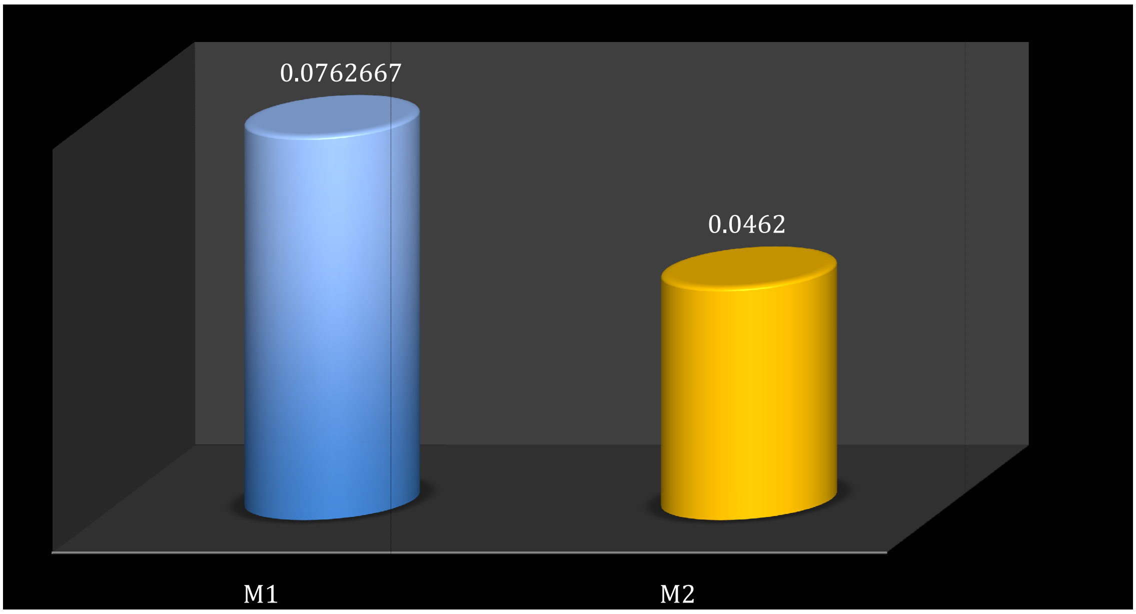


Table 9. Shows the statistical significance between the marginal discrepancy of the coping with die stone model at two different points in the distal aspect of DMLS coping with SEM analysis. It was found that there was no statistically significant difference found between the two sites in the distal side with p>0.05

MLS	Mean	Std. Deviation	Std. Error Mean	t	Sig.
D1	.0461333	.00798987	.00206298	-.563	.582^{NS}
D2	.0471333	.00931870	.00240608		

GRAPH 9

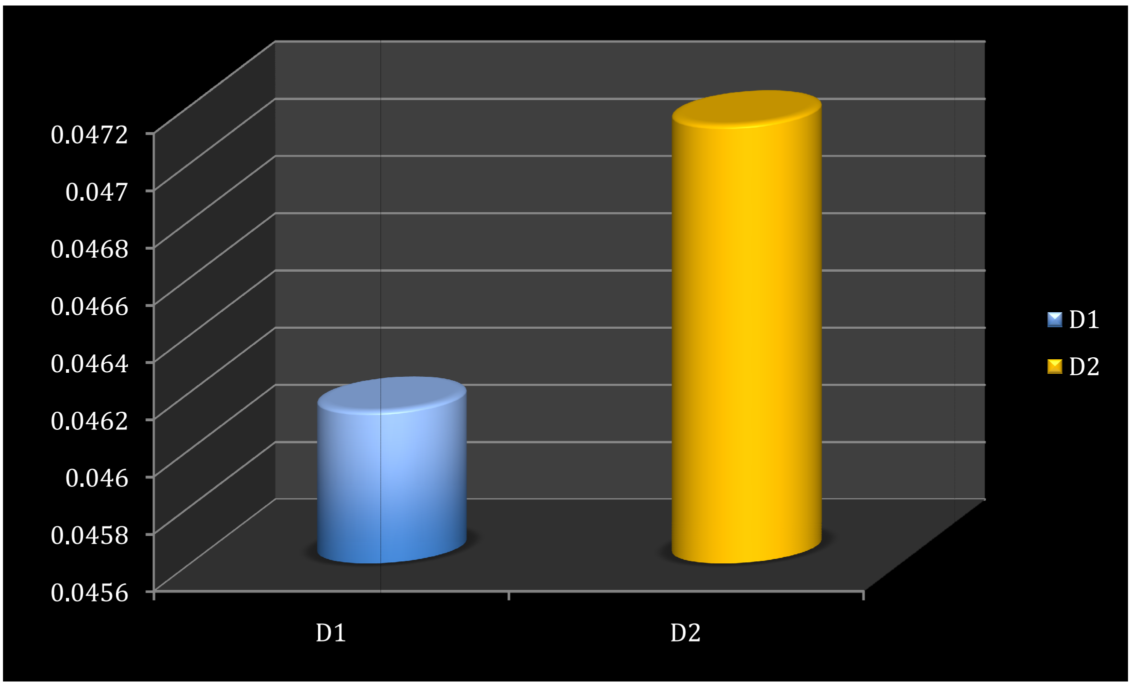


Table 10. The mean marginal discrepancy between coping and the die stone models in MLS method in mesial and distal side – SEM analysis

S.No	Mesial	Distal
1	0.0365	0.037
2	0.05	0.046
3	0.0625	0.05
4	0.0425	0.048
5	0.054	0.065
6	0.0405	0.035
7	0.041	0.048
8	0.0525	0.0385
9	0.0625	0.05
10	0.0365	0.05
11	0.0425	0.041
12	0.045	0.0505
13	0.048	0.0425
14	0.0475	0.0575
15	0.0415	0.0405

GRAPH10:

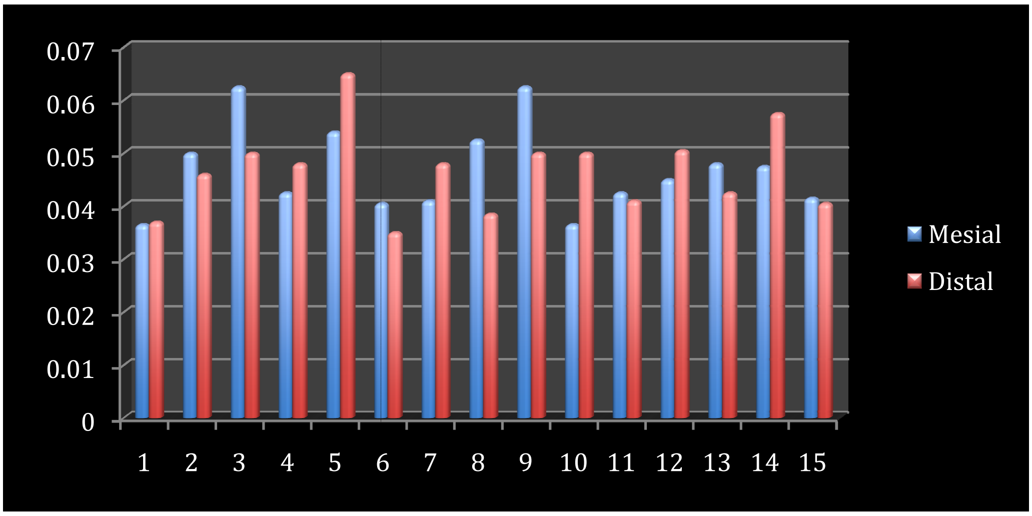


Table 11. Shows the statistical significance between the marginal discrepancy of the coping with die stone model at mesial and distal aspects of DMLS method with SEM analysis. It was found that there was no statistically significant difference found between the two sides with p>0.05

DMLS	Mean	Std. Deviation	Std. Error Mean	T	Sig.
Mesial	.0468667	.00820816	.00211934	.102	.236^{NS}
Distal	.0466333	.00796973	.00205778		

GRAPH 11:

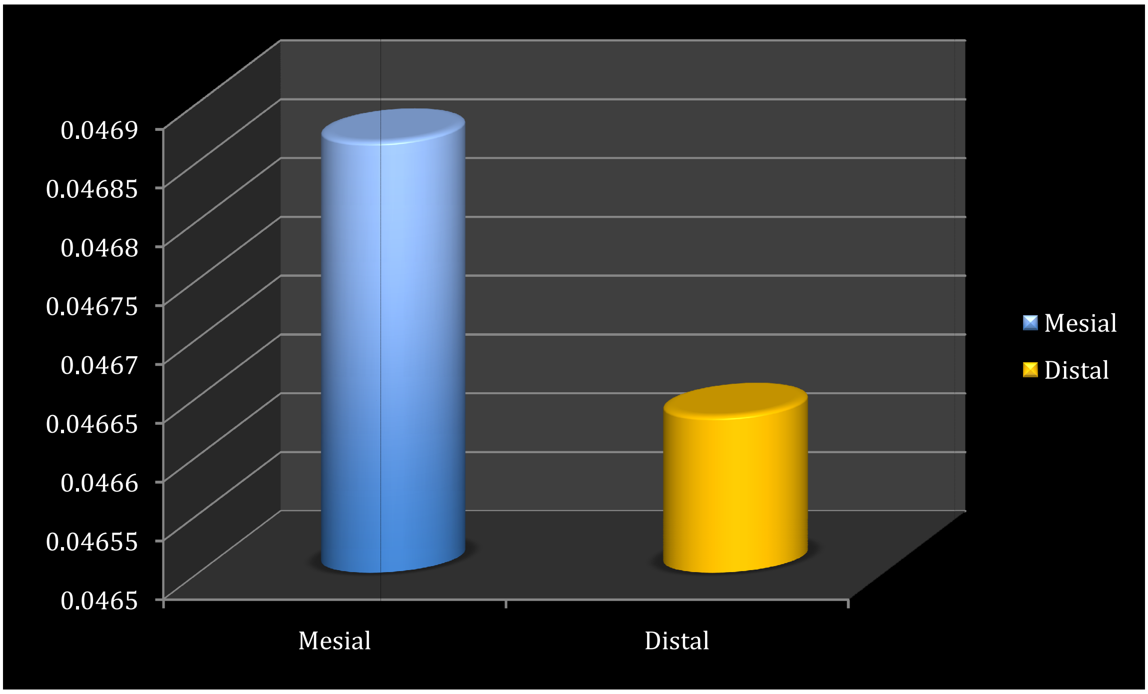


Table 12. Master table showing data entry of SEM images of the marginal discrepancy between coping and the die stone models in LW method at two different points on the mesial and distal side

S.No	M1	M2	D1	D2
1	0.096	0.098	0.101	0.103
2	0.113	0.118	0.108	0.111
3	0.096	0.098	0.101	0.098
4	0.113	0.108	0.119	0.11
5	0.098	0.101	0.113	0.108
6	0.113	0.107	0.122	0.12
7	0.126	0.12	0.118	0.122
8	0.098	0.112	0.103	0.093
9	0.098	0.101	0.113	0.108
10	0.096	0.098	0.098	0.101
11	0.101	0.098	0.098	0.101
12	0.122	0.118	0.19	0.096
13	0.19	0.113	0.107	0.098
14	0.126	0.11	0.096	0.093
15	0.122	0.108	0.098	0.103

GRAPH 12:

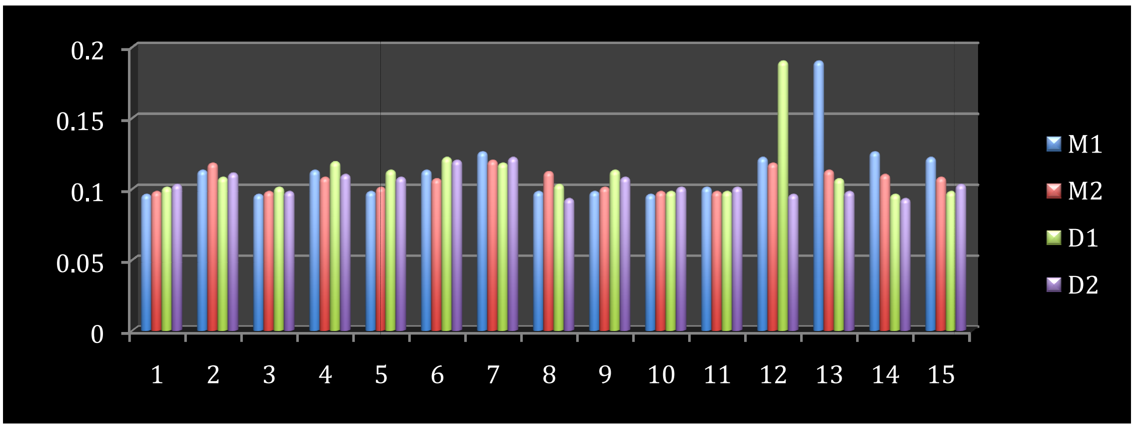


Table 13. Shows the statistical significance between the marginal discrepancies of the coping with die stone model at two different points in the mesial side using Lost Wax method of fabricating the coping with SEM analysis. It was found that there was no statistically significant difference found between the two sites in the mesial side with p>0.05

LW	**Mean**	**Std. Deviation**	**Std. Error Mean**	**t**	**Sig.**
M1	.1138667	.02405905	.00621202	1.238	.236[NS]
M2	.1072000	.00792104	.00204520		

GRAPH 13:

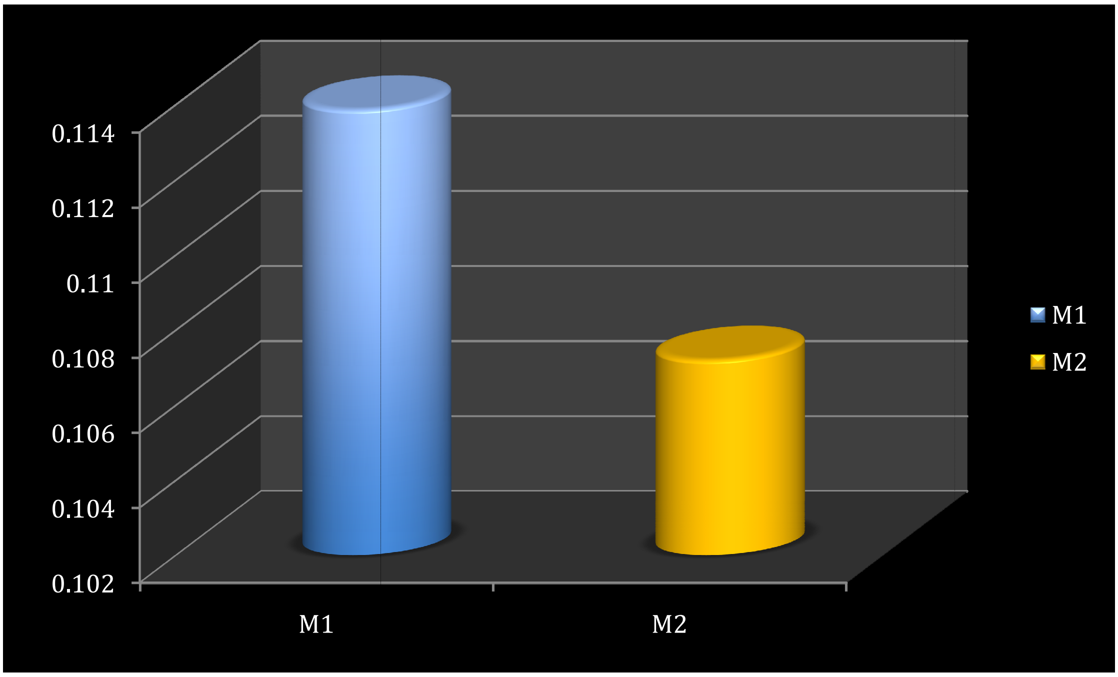


Table 14. Shows the statistical significance between the marginal discrepancy of the coping with die stone model at two different points in the distal aspect of Lost Wax method with SEM analysis. It was found that there was no statistically significant difference found between the two sites in the distal side with p>0.05

LW	Mean	Std. Deviation	Std. Error Mean	t	Sig.
D1	.1123333	.02311050	.00596711	1.274	.223[NS]
D2	.1043333	.00883715	.00228174		

GRAPH14:

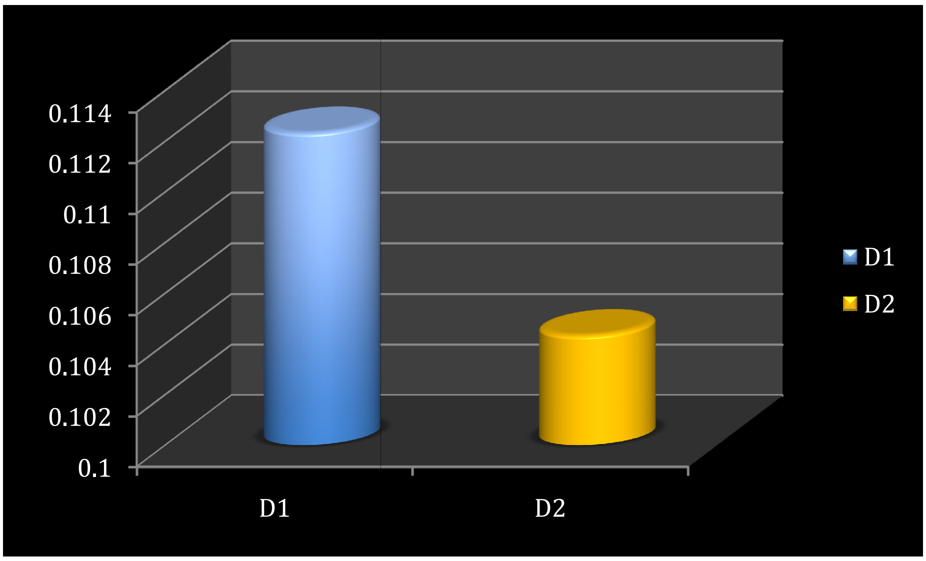


Table 15. The mean marginal discrepancy between copings and the die stone models in LW method on Mesial and distal side – SEM analysis

LW	Mean	Std. Deviation	Std. Error Mean	t	Sig.
Mesial	.1105333	.01456324	.00376021	.496	.628^{NS}
Distal	.1083333	.01257785	.00324759		

GRAPH15:

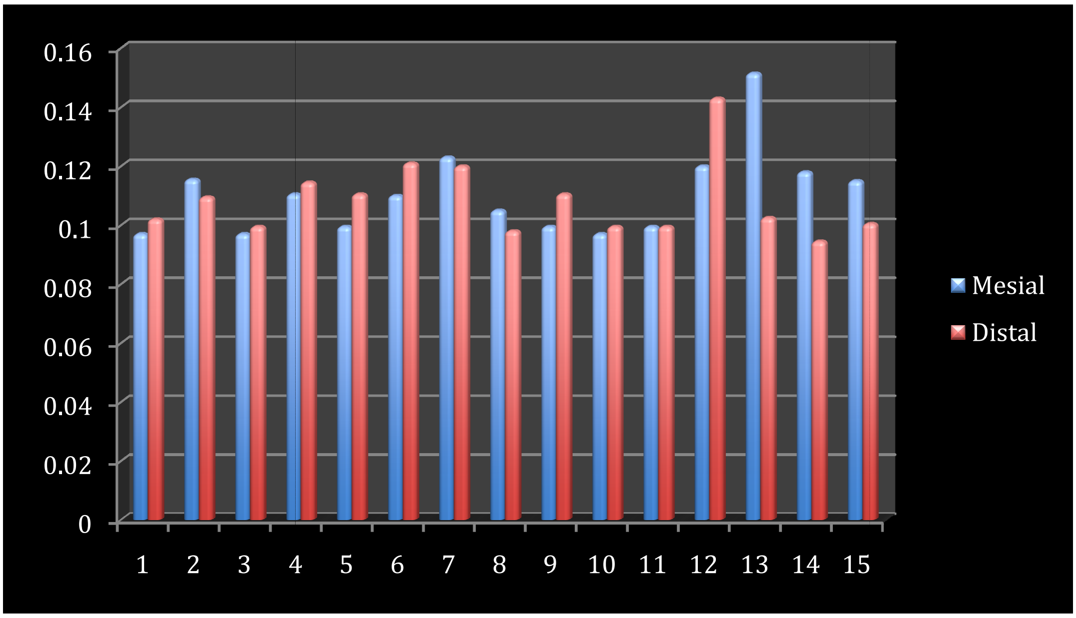


Table16. Shows the statistical significance between the marginal discrepancy of the coping with die stone model at mesial and distal aspect of Lost Wax method with SEM analysis. It was found that there was no statistically significant difference found between the two sides with p>0.05

S.No	Mesial	Distal
1	0.097	0.102
2	0.1155	0.1095
3	0.097	0.0995
4	0.1105	0.1145
5	0.0995	0.1105
6	0.11	0.121
7	0.123	0.12
8	0.105	0.098
9	0.0995	0.1105
10	0.097	0.0995
11	0.0995	0.0995
12	0.12	0.143
13	0.1515	0.1025
14	0.118	0.0945
15	0.115	0.1005

GRAPH16:

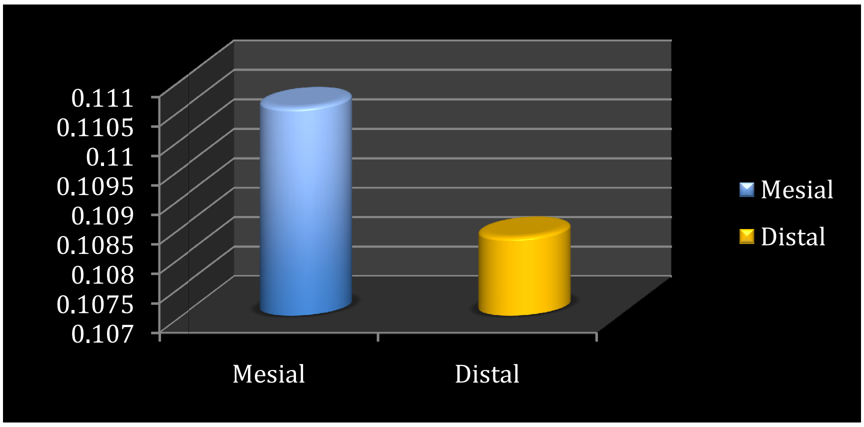


Table 17. The mean marginal discrepancy between coping and the die stone models between MLS and LW method – SEM analysis

S.No	MLS	LW
1	0.03675	0.0995
2	0.048	0.1125
3	0.05625	0.09825
4	0.04525	0.1125
5	0.0595	0.105
6	0.03775	0.1155
7	0.0445	0.1215
8	0.0455	0.1015
9	0.05625	0.105
10	0.04325	0.09825
11	0.04175	0.0995
12	0.04775	0.1315
13	0.04525	0.127
14	0.0525	0.1062
15	0.041	0.1077

GRAPH 17:

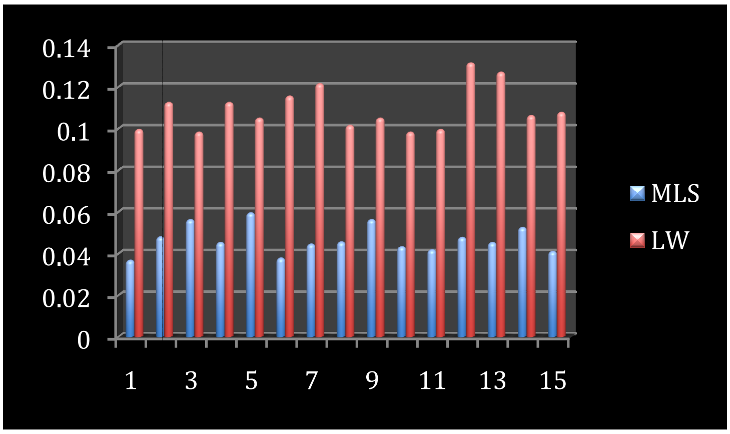
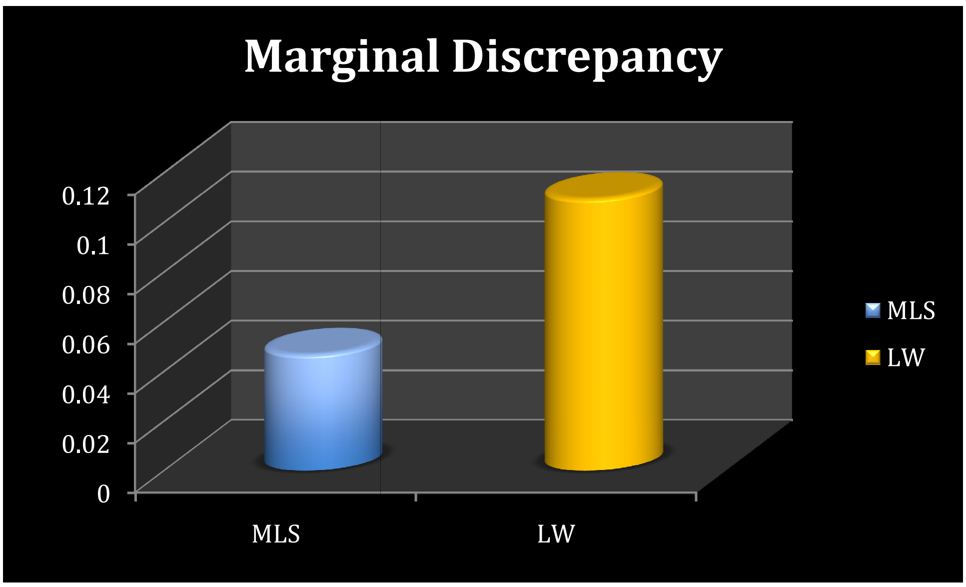


Table18. Shows the statistical significance between the mean marginal discrepancy of the coping with die stone model using DMLS and Lost Wax method of fabricating the coping with SEM analysis. It was found that there is very high statistical significance difference found between the two methods with p<0.05

Parameter	Group	Mean	Std. Deviation	Std. Error Mean	t	Sig.
Mariginal Discrepancy	MLS	.0467500	.00676717	.00174728	-19.360	.000***
	LW	.1094267	.01055572	.00272547		

GRAPH 18:



DISCUSSION:

The marginal fit of the dental restoration is one of the most important criteria when evaluating the clinical acceptability of crowns. Although clinical evaluations of marginal discrepancies have their limitations and inherent errors, it seems to be important to investigate newly developed fabrication technologies. The aim of the current study was to compare the marginal and internal fit of crowns made using laser sintering of Co-Cr alloys powder with crowns made using conventional lost wax technique.

Dimensional accuracy is essential for successful dental casting. The production of accurate dental castings by lost wax technique involves casting molten alloy into a refractory mold. Dr. William H. Taggart in 1907 [3] introduced lost wax casting technique for casting alloys. Even though it is widely accepted and used, this particular method is technique sensitive[20,47]. Ideally, cemented crown margins meet prepared tooth margins in a perfect non-detectable junction. Clinically it is difficult to achieve and verify. The term marginal gap does not have a single definition. Holmes et al[20], proposed a definition according to contour difference between the crown and tooth margin, states that " The perpendicular measurement from inner surface of casting to the axial wall of preparation is called internal gap, and the same measurement at the margin is called marginal gap''. Increase in internal space thickness will lead to compromised retention.

Historically the most desirable location for cervical margin has been debated but most favored is supra or equigingival placement whenever possible. Some believe that the sub gingival margins irrespective of quality are detrimental to gingival health as they approach the base of gingival crevice. The location and fit of cervical margins of crown are important to biological or mechanical failure of restorations. Margins incorporating an inclined vertical configuration have been recommended to minimize these problems [23]. The present study was done to simulate a supra-gingival margin where vertical gap which expose cement to the oral environment was measured.

There are many clinical and laboratory factors responsible for the marginal and internal adaptation of dental cast restorations. Technical errors such as damage to the margins during die trimming, excessive thickness of die spacer, inaccurate wax adaptation, incorrect investment and casting failures may occur[7]. Some authors recommend certain methods and techniques to minimize marginal and internal fit inaccuracies. They include over-waxing the margin of wax pattern, removing wax from internal surface of wax pattern[15], die relief with application of die spacer, internal relief of cast restoration by sandblasting, mechanical milling, acid etching, electrochemical milling and occlusal venting for escape of restoration.[4,20,45]

The properties of the casting materials also cause casting inaccuracies. Wax, which had been used over many decades, has shrinkage and stress relaxation properties and resins have polymerization shrinkage.[24] Noble metals were preferred for casting, which were replaced by base metal alloys like Ni-Cr and Co-Cr, due to high expense of the noble metals. A common problem with base metal alloys is undersized casting as a result of greater thermal contraction from higher solidification temperatures, than those of noble metals .[54] Co-Cr alloys were primarily used for cast partial dentures. Currently they are also used more commonly than Ni-Cr alloys for fixed prosthesis. Co-Cr alloys contain predominantly cobalt and sometimes tungsten in small amounts and possess high rigidity and hardness. Electrochemical studies show that Co-Cr alloys are more resistant to corrosion than Ni-Cr alloys. Nickel based alloys also have greater sensitization potential than cobalt chromium alloys, whereas Co-Cr alloys allergies are rare.[30,49] Hence Co-Cr was selected as the material of choice for this study.

Many studies have been done to improve the fit of the cast restoration. Multiple protocols to minimize errors and yield best internal and marginal fit of the cast restoration also had been suggested.[51] However very few studies have reported about obtaining metal copings directly using CAD/CAM technique.[12,56] Studies comparing discrepancies of the copings made using conventional casting and DMLS is also lacking. The present in vitro study was conducted to compare and evaluate the marginal gap and the internal gap of Co-Cr copings fabricated by conventional casting procedures and with direct metal laser sintering (DMLS) technique before and after ceramic firing cycles.

A standardized custom-made stainless steel master model was made based on model recommended by Anders Ortorp et al [1] in their study. Model used in this study had a 360° chamfer margin with 16° total occlusal convergence. A two-stage impression of the master model with polyvinyl siloxane was made and 30 master die was made using type IV die stone. These 30 individual master die were used for fabricating all the 30 patterns used in this study. Many of the previous studies had used single die for fabricating all the copings involving multiple laboratory steps on a single die, which leads to wear and dimensional inaccuracies of the die, thus incorporating more error in the study. Hence 30 individual master die models were prepared.

A total of 30 samples, 15 each of both the lost wax and DMLS technique were made. Fifteen samples obtained using lost wax pattern were subjected to casting procedures and fifteen Co-Cr cast copings were obtained. These fifteen samples were then divested, sand blasted and steam cleaned. These completed test samples were grouped as G1 (LW). Remaining fifteen samples were sandblasted, steam cleaned and grouped as G2 (DMLS).

There are various methods to evaluate the adaptation of prosthetic restorations. They include the use of laser videography, profile projector, micro-CT, CAD/CAM scanner and scanning electron microscopy[9,14,42]. The replica technique (RT), or cement analog technique has been widely used because of its ability to estimate the internal and marginal gap dimension of prosthetic restoration. This technique is non-destructive and uses an impression material instead of the cement to seat a restoration over the prepared die. After setting, the impression material and restoration are carefully separated from the die and the thickness of the cement layer analog is measured[26]. Another non- destructive method that can be used to evaluate the gap dimension of prosthetic restoration is the “weight technique” (WT). It has lower cost and it is easier to execute than the replica technique[10]. In the weight technique the impression material that simulates the cement layer is weighted instead of measuring the thickness in specific points as for the “replica technique”. The value obtained with the weight technique (WT) corresponds to the total internal gap thickness between the restoration and the prepared die. This study evaluated the volumetric analysis of internal 3 dimensional gap using “WT” silicone and the marginal gap using “RT” with SEM.

All the test samples of each group was coated on the internal surface with a thin layer of silicone pressure indicating paste (fit checker) and seated on stainless steel master model using finger pressure[45]. Kokubo et al[29] recently used a light-body silicone in place of luting cement to determine relative marginal gap for ceramic crowns. McLean and Von Fraunhofer[31] previously used a light-body silicone to estimate cement film thickness. The use of light-body silicone for internal fit evaluation of dental crowns is a convenient method, since a relative measurement of cement mass is obtained for the 3-dimensional volume of the luting cement region. Nakamura et al [35] used test-fit silicone paste for measurement of internal gaps as well. Internal fit was evaluated using weighing silicone material corresponding to the volume of the luting cement in 3 dimensions. This technique was chosen because measurements could be repeated easily after ceramic firing and at final clinical try-in. Even though this method simulates the cementation of fixed restorations clinically, it should be emphasized that the use of finger pressure is variable. After the material set the excess was removed using a size 12 Bard Parker blade. Silicone pressure indicating paste was used because it was easy to be removed from inner surface without damaging the inner surface of the copings. Metal copings were then removed from the die and the silicon copings on the inner surface were removed carefully and weighed on an electronic weighing machine. The weight of the silicone material between the crown and master die was significantly lower for the laser-sintered group of Co-Cr alloy crowns.

The basic data obtained from this study about the weight (μg) of the silicone coping for volumetric analysis for pre-firing (G1-LW) group was 0.034 and post firing (G1-LW) group 0.037 (Table 1 and 2). Pre-firing (G2-DMLS) was 0.023 and post-firing (G2-DMLS) was 0.026 (Table 3 and 4). Tables 5 and 6 show a comparatively significant difference of internal gap dimension between lost wax (G1-LW) samples compared to direct metal laser sintered (G2-DMLS) samples, both pre-firing and post-firing with ceramics. This could be attributed to the fact that DMLS process have completely eliminated casting and manual errors, yields good results, compared to induction coil casting procedure which was used to melt the alloy for lost wax technique. The induction coil heating melts alloy at higher temperature than its melting range, which causes the alloy to lose its low melting point compositional elements making it more viscous and affecting its flow. Another factor is the delayed time to melt alloy in an electrical machine, a condition that can also modify the alloys composition and consequent viscosity[32].

Marginal fit of cast restoration is one of the most researched subjects in fixed prosthodontics. Mc lean et al [31] concluded from their study that after casting, marginal gap ranged from 40-61.5μm. It has also been suggested by other studies that marginal gap of 120μm is the maximum clinically acceptable gap .Hung et al [22] reported that practical range for clinical acceptability of fit seems to be approximately 50 to 75μm. Results of the present study regarding mean internal gap by volumetric analysis for all the samples were within acceptable range and are in consensus with those of Yurdanur et al[56] and Mc Lean et al[31].

The marginal fit of both (LW and DMLS) post-firing samples were evaluated after embedding the specimens in acrylic resin for stabilization and sectioned the specimens into two slices. Measurements were done using a scanning electron microscope in mesio-distal region in predetermined locations, on each proximal wall.

Table 7-13 shows the data of SEM images of the marginal discrepancies between the post firing metal ceramic coping and die stone models for both lost wax (LW) and direct metal laser sintering (DMLS) techniques. There is no statistically significant difference ($P>0.05$) found between the two points M1 and M2 in the mesial side, D1 and D2 in the distal side for both the samples. Also it was found that the mean marginal gap between (G1-LW) and (G2-DMLS) for pre and post firing metal ceramic copings show very high statistically significant difference.

The internal stresses produced by cervical wax and the discrepancy between mould expansion and casting shrinkage could be the reason for this high difference of values. Also the composition of Co-Cr alloy used for laser sintering bear lower molybdenum content compared to Co-Cr alloy used for conventional casting thereby reducing the melting range.

Bindl and W.H Mormann[6] reported internal gap width of 81µm to 136µm for different all-ceramic CAD /CAM crown copings, and found a significant difference between veneered and non-veneered copings. This significant difference between pre-fired (non-veneered) and post fired (veneered) copings were present in this study.

Groten et al [18] reported that approximately 50 measurements were needed for clinically relevant information about the gap size regardless of the gap definition or cementation condition. In this study 4 predetermined points were used for the evaluation of internal gap. More number of readings could yield better results.

Future research should include measurement of the mechanical properties and the surface characteristics of the laser sintered Co-Cr alloy, along with investigation of the biocompatibility of the crowns prepared by laser sintering.

Limitations of the study:

1. This is an in vitro study which cannot simulate oral conditions.
2. Though 3 dimensional evaluation of the internal gap by weighing method done, the internal gap was not measured individually at more predetermined reference areas like occlusal and axial surfaces.
3. Finger pressure has been used for cementation procedure of metal copings. Though this method simulates the cementation of restorations clinically, it should be emphasized that use of finger pressure is variable.
4. It is important to assess the adaptation of CAD / CAM systems as only few studies have been reported regarding the CAD / CAM scanner and milling units.

Nevertheless several limitations mentioned above, this in-vitro study suggested marginal fit of cast copings with two different fabrication techniques were within the range of clinically acceptable values as mentioned in the literatures.

In this in-vitro study the copings obtained from DMLS technique showed the least marginal gap when compared to lost wax copings. So further studies on this newly introduced DMLS technology should be carried out with various parameters to obtain confirmative and consistent estimate of the marginal and internal discrepancy with these techniques for their acceptance in dentistry.

Summary

An in vitro study was conducted to compare the marginal and internal gap of Co-Cr copings fabricated by two methods, (conventional lost wax technique and Direct laser sintering).

A total of 30 test samples were fabricated using Co-Cr alloys in two different techniques. All the samples were made by making an impression from a stainless steel master model.15 cast copings were fabricated from patterns obtained by inlay-casting wax for conventional lost wax technique. 15 copings were obtained from 3D printing for fabricating DMLS copings. Patterns made from inlay wax were invested, burnout and casting was done by traditional method with Co-Cr alloy to obtain cast copings. Cast copings were divested, sandblasted, steam cleaned and finished. Copings prepared from DLMS technique were also sandblasted and steam cleaned.

The entire copings were then cemented on the stainless steel master model using silicone pressure indicating paste to simulate a coping cemented in the oral condition. The test samples were removed from the master model, and the silicon coping was separated from the inner surface of test samples. The silicon copings thus obtained were evaluated for internal gap using an electronic analytical weighing machine (Schimadzu, Japan). All the measurements were determined in micro grams (µg). Later the test samples were cemented onto their respective dies with GIC type I luting cement (GC, FUJI Japan). These cemented specimens were sectioned mesio-distally. The marginal gap was measured in 2 pre-determined reference points using a Scanning electron microscope (Sigma V, Carl Zeiss, Munich, Germany), All the measurements were determined in micrometers (µm).

The manufacturing process influences marginal and internal accuracy of the dental restorations. An increase in marginal gap exposes the cement to the oral environment thereby affecting the health of the remaining supporting structures and increase in internal gap can affect the restoration. Hence both are important parameters to be considered for longevity of a restoration. Results of this study showed the marginal gap of Co-Cr copings obtained by two different fabrication techniques were within the clinically acceptable range (10-160µm).

The internal gap of Co-Cr copings were obtained from two different techniques were also within the clinically acceptable range (81-136µm)

In this study a new fabricating procedure (DMLS) was used for the fabrication of Co-Cr copings. The marginal gap of the Co-Cr coping obtained by this technique was (32µm) least compared to the lost wax technique (112µm). Though results obtained in this in vitro study fell within the clinically acceptable range, the DMLS technique had an advantage over the lost wax technique, as it exhibited minimal gap in the marginal region, an area of chief concern.

In terms of marginal fit and internal fit, both the conventional casting technique and DMLS technique have yielded results within clinically acceptable range but the difficulties encountered during conventional casting procedures are being completely eliminated in DMLS technique which seems to yield promising results.

The scope of further studies regarding the mechanical properties and biocompatibility of laser sintered Co-Cr would be of great use for their acceptance in dental laboratory and practice

Conclusion

This in-vitro study was conducted to compare pre and post-firing of the internal fit of Co-Cr coping fabricated by conventional lost wax technique (LW) and direct metal laser sintering (DMLS) technique.

1. The internal gap of 15 pre-firing Co-Cr copings of the lost wax (G1-LW) showed a mean value of 34µg.
2. The internal gap of 15 post-firing Co-Cr copings of lost wax (G1-LW) showed a mean value of 37µg.
3. The internal gap of 15 pre-firing Co-Cr copings of the DMLS (G2-DMLS) showed a mean value of 23µg.
4. The internal gap of 15 post-firing Co-Cr copings of DMLS (G2-DMLS) showed a mean value of 26µg.
5. The marginal gap of the 15 Co-Cr copings obtained from Lost-wax (G1-LW) technique showed a mean value of 109µm.
6. The marginal gap of the 15 Co-Cr copings obtained from DMLS (G2-DMLS) technique showed a mean value of 46µm.

From the above data the study concluded that the mean internal gap between (G1-LW) and (G2-DMLS) for pre and post firing metal ceramic copings show statistically significant difference. Also it was found that the mean marginal gap between (G1-LW) and (G2-DMLS) for post firing metal ceramic copings show very high statistically significant difference.

Conventional casting technique and DMLS have yielded results within clinically acceptable range, but compared to conventional casting methods, the technique sensitive procedures are being completely eliminated in the DMLS technique.

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